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VOLUME 14 DECEMBER 1935 NUMBER 12

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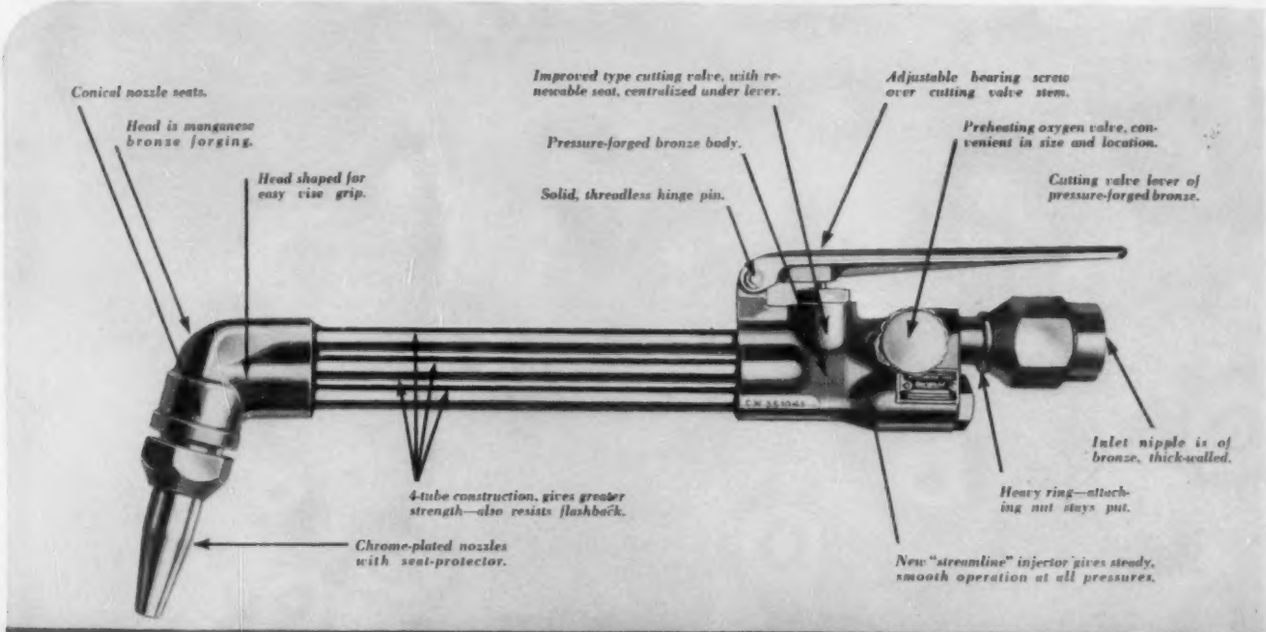
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THE
AMERICAN WELDING SOCIETY
JOURNAL

WM. SPRARAGEN, Editor | VOL. 14 | NO. 12

DECEMBER

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Bend Testing of Welds—A Summary*

By M. F. SAYRE†

This paper represents a partial report on studies on methods of tests of welding carried on at Union College under a committee composed of Mr. H. M. Hobart, Mr. A. Vogel and Professor M. F. Sayre, with Mr. Herman Munz as assistant, with the aid of a grant from the National Research Council.

The aim of this work was to assemble at one point the available published material on various welding tests and to aid in suggesting the fields of laboratory investigation in which work could fruitfully be done in the future. The first step was to bring together a bibliography of published material containing some 700 titles, with brief abstracts in nearly all cases. In making up this bibliography, full use was made of sources like the Institute of Metals Abstracts, the Iron and Steel Institute Abstracts and the Engineering Index, and to this list many other titles have been added. The individual sheets in this bibliography have been keyed to indicate the apparent relative importance of the article and the types of tests described in it. Copies of this bibliography have been placed on file in the Engineering Societies Library in New York, the Carnegie Library in Pittsburgh and the Headquarters of the AMERICAN WELDING SOCIETY. An analysis of the information obtained in preparing the bibliography appeared in the AMERICAN WELDING SOCIETY JOURNAL for August.

Because of the active discussion now going on regarding the advisability of certain features of the American specifications for bend testing and because of the wealth of information available particularly in Germany regarding this test, which is not now easily available to American engineers, this type of test was chosen for immediate attention following completion of the bibliography. Abstracts or complete translations were made of available foreign specifications for weld testing and of a number of foreign discussions, and these will also be placed on file. On this information the accompanying summary of bend testing methods has been based.

THE bend test has a long and honorable history as a means of determining quality of metal. Because of the simplicity of carrying out the test itself and of the ease of interpreting the results, it was almost certainly one of the methods used by the earliest prehistoric ironworker to gage the excellence of the product of his primitive furnace.

One of the reasons for its early use was its effectiveness as a means of trying out the properties of old time forge welds. As compared to the tension test, it was much easier to concentrate attention on the weld itself, and, further, the type of stresses introduced was more effective in opening out seams or fissures in the weld and in emphasizing differences in characteristics between weld and parent metal. These same properties have led to its continued use with arc and gas welds as well.

A major disadvantage of the bend test in its original simple form was the fact that the results were inherently qualitative rather than quantitative in nature, and the main problem in the development of bend testing has been to devise means of so controlling technique as to permit of obtaining reliable quantitative figures while retaining as far as possible its advantages of simplicity and ease of execution. Two basically different methods of doing this have been developed, one in Europe, the other in this country, and various other modified forms have been suggested. During the past four years many papers discussing these different methods have appeared, particularly in Germany and England, and a summary of these papers should be of advantage to American readers.

*Presented at Fall Meeting, A. W. S., Chicago, week of Sept. 30, 1935.

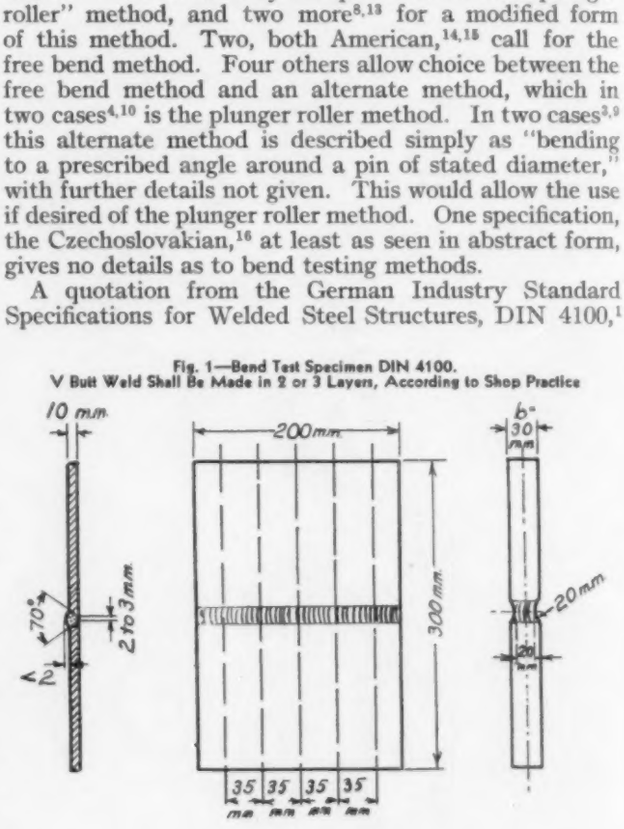
†Assoc. Prof. of Applied Mechanics, Union College, Schenectady, New York. A contribution to the work of the Fundamental Research Committee.

Bend Testing Specifications Now in Use

Present practice in bend testing as distinguished from theory is best given through a résumé of the contents of various welding or materials testing specifications. Sixteen of these as listed in the accompanying bibliography[1 to 16] have been studied. Seven of these[1,2,5,6,7,11,12] call for use of what may be spoken of as the "plunger roller" method, and two more[8,13] for a modified form of this method. Two, both American,[14,15] call for the free bend method. Four others allow choice between the free bend method and an alternate method, which in two cases[4,10] is the plunger roller method. In two cases[3,9] this alternate method is described simply as "bending to a prescribed angle around a pin of stated diameter," with further details not given. This would allow the use if desired of the plunger roller method. One specification, the Czechoslovakian,[16] at least as seen in abstract form, gives no details as to bend testing methods.

A quotation from the German Industry Standard Specifications for Welded Steel Structures, DIN 4100,[1]

Fig. 1—Bend Test Specimen DIN 4100.
V Butt Weld Shall Be Made in 2 or 3 Layers, According to Shop Practice



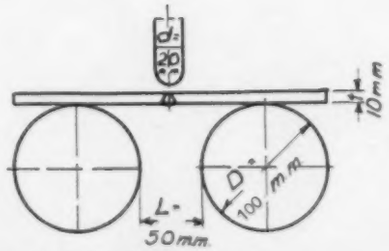


Fig. 2—Bend Test Device, DIN 4100.
Vertex Side of Weld at Plunger to Be Milled or Ground Flat

Table 1—Summary of Specifications, Plunger Roller Device

Ref. No.		t mm.	b mm.	D mm.	d mm.	L mm.	Over-all Length mm.	Angle of Bend	Bead
(1)*	DIN 4100	10	30	100	20	50	300	50°	(*g*)
(2)	German Gov. RR	10	35	50	20	50	250	(*a*)	(*g*)
(4)	German Electrodes**	to 12	35–40	50	2*t*	5*t*	220	(*b*)	(*h*)
		Over 12	35–40	100	2*t*	5*t*	220	(*b*)	(*h*)
(5)	French Electrodes	10	...	5*t*	2*t*	5*t*	150–250	(*c*)	(*h*)
(6)	French Structures	8–10	40	50	20	50	250	45°	...
(7)	French Ships	10	30?	50	20	50	150–200	(*d*)	...
(10)	Polish**	10–12	30–35	100	3*t*	50	300	60°	(*e*)
		in.	in.	in.	in.	in.	in.		
(11)	British	...	3*t*	2.5	4*t*	7*t*	16	90°	(2)
(12)	Metropolitan-Vickers	0.375	1.875	1.875	0.5	3.75	...	...	...
(16)	Scholer Device	...	...	12	(*f*)	$d+2t$	...	...	...

(*a*) Variable, 15° to 180° depending on type of electrode.
(*b*) Variable, 45° to 180° depending on type of electrode.
(*c*) Dependent on specifications for individual electrodes.
(*d*) Greater than 60° for electrodes of Type 1 (for structures of major importance), and greater than 45° for electrodes of Type 2.
(*e*) Bottom of weld "slightly evened."
(*f*) Variable, dependent on *t*.
(*g*) Bead removed on vertex only.
(*h*) Bead removed on both faces.

NOTE: In practically all of these specifications a requirement is included that sharp edges of the test piece near the weld shall be filed or ground to remove roughness.

* See bibliography.

** Alternative use of free bend method allowed.

will serve as a good explanation of the plunger roller method.

"Two plates (strength 3700 to 4500 kg./cm.²) shall be fused together by means of a V-weld. The fusion planes shall form an angle of about 70°. From this test plate, test specimens shall be cut (Fig. 1). These specimens shall be tested for tension, and for bending as described below. In the tensile test, the weld strength must reach at least the limit of 3000 kg./cm.², the thickness of the weld '*a*' being assumed equal to the thickness of the plate '*t*.' The bend test shall be conducted according to Fig. 2. Prior to the test the surface of the vertex of the weld shall be milled or ground flat. The specimen shall be bent to an angle of at least 50° before incipient cracking occurs."

Table 1 gives details as to diameter of roller D, clear spacing between rollers L, diameter of plunger end d and thickness t, width b and over-all length of specimen s, for the seven specifications which require use of the plunger roller method, and for the two specifications (German electrodes,[4] and Polish,[10]) which give details for this method while allowing use of a form of free bend method as an alternative. Dimensions are also given for the plunger roller bend testing device recently developed by Prof. C. H. Scholer of the Kansas State Agricultural College.

It should be noted that in most cases these specifications definitely limit the thickness of the test specimen to 10 mm. or to its essential equivalent, 0.375 in. The breadth of specimen is either 30, 35 or 40 mm., or, as in the Metropolitan-Vickers specification, 1.875 in. It is apparently not anticipated that tests will be made upon thicker specimens. The spacing between rollers is in general stated to be either 50 mm. or five times the thickness of the specimen, with the thickness of the plunger 20 mm. or 2 *t*. This leaves ample space for the specimen to be forced down between the rollers, producing a full 180° angle of bend. The one case where the 180° angle cannot be obtained is under the Polish specifications,[10] where the spacing between rollers is stated to be 50 mm., the thickness of bars 10 to 12 mm. and the thickness of plunger 3 *t*.

Two other foreign specifications deserve special notice. In the Australian Standard Specification for Electrodes for Metallic Arc Welding, which forms Appendix 3 to the code for Metallic Arc Welding in Steel Buildings[12] the bend test piece is "made by depositing weld metal on a mild steel plate $^3/_8$ in. in thickness, 8 in. long and 3 in. in width, and then machining off the weld metal until the specimen is perfectly smooth, $^1/_2$ in. in thickness and $^3/_4$ in. in width (Fig. 3). Gage marks shall be scribed on

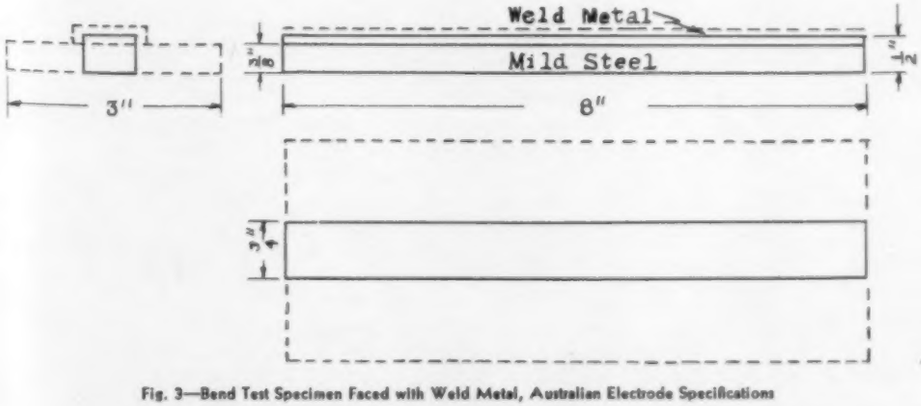


Fig. 3—Bend Test Specimen Faced with Weld Metal, Australian Electrode Specifications

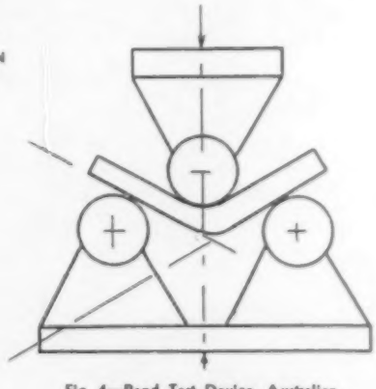


Fig. 4—Bend Test Device, Australian Electrode Specifications

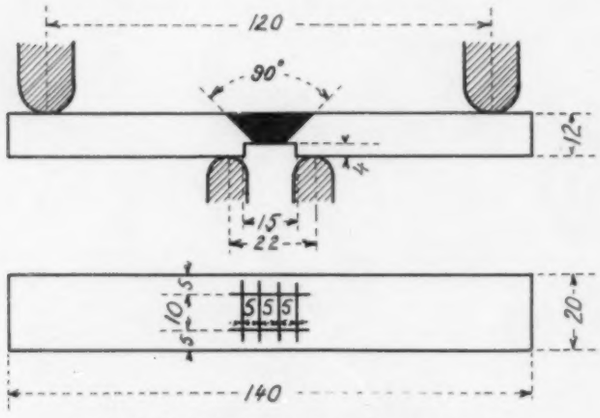


Fig. 5—Notched Static Bend Specimen, Hungarian Specifications
Dimensions in mm.

the weld metal at $^1/_2$-in. intervals. The specimen shall then be slowly bent cold round a roller 1 $^1/_2$ in. in diameter, by loading it at two points outside the position of the roller, by insertion between the compression platens of a testing machine as indicated in Fig. 4."

The Hungarian Specifications for Welded Steel High Buildings[8] call for a special form of notched test specimen loaded as shown in Fig. 5. "In order to insure that the bending shall be limited to the weld, the 20-mm. wide by 12-mm. thick test bar is machined to a depth of 4 mm. immediately below the weld. Before the bending, four cross lines 5 mm. apart are scribed on the tension side of the weld, and two longitudinal lines 10 mm. apart. The test bar is bent until a crack 5 mm. long appears on the tension side. The weld is considered as satisfactory if the mean value of elongation of three test bars is at least 12%, and the individual elongations over 5-mm. gage lengths between the individual scratches are greater than 10%."

The American type of free bend test as called for in the A. S. M. E. Boiler Construction Code[15] and in the Tentative Method of Bend Test for Ductility of Metals, A.S.T.M.—E 16,[14] is too well known to call for very detailed description. Initial bends of 5° to 30° are first given to the specimen at the third points (Fig. 6). The specimen is then placed in a vise or press as a strut and compression applied at the ends. The vise or press is closed until failure of the outside fibers occurs. Under the A. S. M. E. code a rectangular specimen is used with breadth equal to 1.5 times the thickness. The bar may be of any convenient length but the weld must be at the mid point of the length. A gage length is marked on the specimen $^1/_8$ in. shorter than the width of the face of the weld and

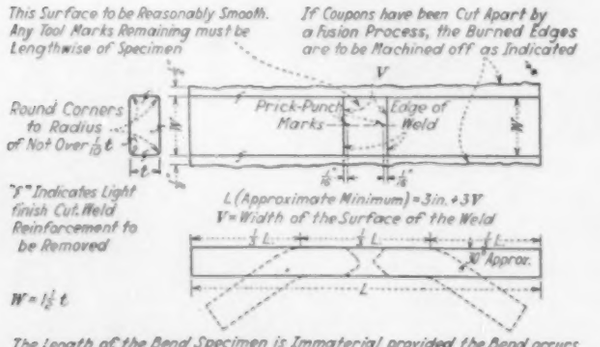

This Surface to be Reasonably Smooth. Any Tool Marks Remaining must be Lengthwise of Specimen
If Coupons have been Cut Apart by a fusion Process, the Burned Edges are to be Machined off as Indicated
V
Round Corners to Radius of Not Over 1/10 t
Prick-Punch Marks
Edge of Weld
"S" Indicates Light finish Cut. Weld Reinforcement to be Removed
L (Approximate Minimum) = 3 in. + 3V
V = Width of the Surface of the Weld
W = 1 1/2 t
Approx.
The Length of the Bend Specimen is Immaterial provided the Bend occurs at the Weld. The Minimum Length indicated is only Suggestive and is Not Mandatory

FIG. U-16. SPECIMEN FOR FREE-BEND TEST

Fig. 6—Free Bend Specimen, A. S. M. E. Boiler Code

per cent elongation is determined by measuring over this gage length using a flexible scale and allowing for the width of any cracks included in the final gage length.

A. S. T. M. Specification E 16, which covers methods of bend testing in general as differentiated from bend testing of welds, calls for rectangular specimens with widths at least three times the thickness. For bars 0.25 to 0.50 in. thick, elongation is measured over a gage length of 0.3 in. A gage length of 1 in. is recommended for thicker plates. The A. S. T. M. specification states that "round bars may be tested by this method but the results will be only comparative, as for the same material the fiber elongation is found to vary slightly with the diameter."

The German Industry Standard for Methods of Tests of Materials, DIN 1605,[8] adopted in June 1924, reads as follows:

"The folding operation shall be performed slowly and steadily in the compression machine, and the bend specimen (*a*) shall be bent to a prescribed angle α around a pin of a stated diameter D (see Fig. 7) or (*b*) the bending shall be started around a pin of optional diameter, and then bending shall be continued by applying pressure

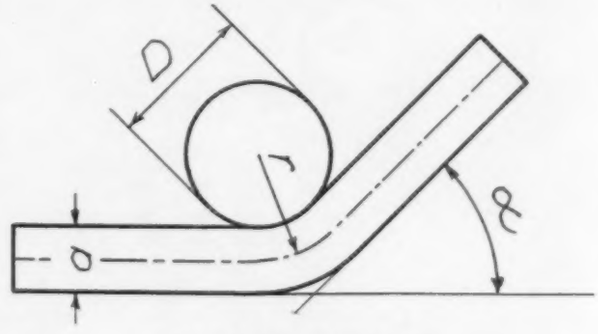


Fig. 7—Bend Test Method DIN 1605

upon the ends of the specimen either until complete 180° bend is obtained or until incipient cracking occurs at the outside fiber. In tests by method (*a*) (bending around a pin) the specimen is considered to meet the specifications if no incipient crack (tension fissures in the metallic material) occurs on the tension side under a prescribed bending angle α. In tests by method (*b*) (free bending), the so-called Tetmayer's bending value, $B_g = 50\ a/r$, is used for evaluation. In this formula the smallest bending radius is employed, which is measured inside by means of a plug gage, or outside by means of a plate gage at incipient cracking. Here '*a*' designates the thickness of the specimen, and '*r*' the mean bending radius of curvature, measured to center line of the specimen."

The specification for materials testing circulated for discussion by the Italian National Committee for the Standardization of Industry in 1934[9] in its bend testing section virtually duplicates DIN 1605, indicating that the two methods allowed by DIN 1605 are probably at the present time in parallel use in Italy.

This summary of existing specifications exphasizes the fact that a broad difference of opinion exists as to the best method of causing the bend and as to the best method of evaluating the results after the bar has been bent. For the latter, angle of bend, radius of curvature and per cent elongation of the outside fiber are all in use. To bend the specimen, both the free bend and the plunger roller method are in use, plus a modified plunger method in the Hungarian specifications (see Fig. 5) which in theory approximates to placing the width of the weld

under a relatively uniform bending moment rather than a variable moment.

Discussion of Bend Test Methods

The last four years have seen in this country, in England and particularly in Germany a very active discussion regarding various phases of bend testing, with many papers published. These papers may in general be classified under the following heads: (1) fundamental discussions of the behavior of welded joints when tested in bending and in tension; (2) discussion of details necessary for successful results in connection with the use of the standard methods of bend testing already listed; and (3) proposals for major modifications in these methods.

The most important paper of the first class is probably one by Mies.[28] He emphasizes, among other things, the effect which a difference in yield strength between weld metal and base metal will have upon the elongation distribution around the bend and so upon the total bend angle and also upon the total elongation obtained in the weld itself. With the deposited weld metal higher in strength than the adjacent annealed base metal, as is likely to be the case, the weld itself will not begin to bend until after appreciable distortion has occurred in the base metal. In a limiting case the weld metal may behave purely elastically and so have a triangular stress-strain diagram each side of the neutral axis even after the adjacent base metal has become so deformed as to cause plastic yield to advance virtually to the neutral axis, resulting in an almost rectangular stress-strain diagram each side of the neutral axis as shown in Fig. 8*a*. In the first case, theoretically, moment = stress times $bt^2/6$ as compared to moment = stress times $bt^2/4$ for the second case, where b and t are respectively the width and thickness of the strip. Assuming that the weld reinforcement has been removed before test, this rigid behavior of the weld metal would occur therefore in all cases where the yield point of the weld metal ran 50% higher than that of the base metal. With weld reinforcement left on, a smaller excess strength would be necessary. In limiting cases like this it would therefore be possible to have a large bending angle without at the same time causing any real plastic yield in the weld or determining the true potential elongation ability of the weld metal, as shown in Figs. 8*b* and 8*c*. In this case the numerical value of the bend angle would give an unduly high impression as to the ductility of the bend, while measurements of per cent elongation in the weld would give an unduly low impression. Obviously, extreme cases of this type would not often occur but much smaller per cent variations in yield point between weld and adjacent metal would nevertheless give trouble. Dr. Daeves[30] describes cases of this kind in which he has used as base metals steels of three different types and in connection with each one three grades of welding wire, a normal grade, a somewhat harder grade and a high strength less ductile alloyed wire. In each case with the high strength welding wires the ultimate strength in a tensile test becomes greater. The yield point, which is determined by the base metal rather than by the weld metal, remains unchanged. The apparent elongation (over a gage length long enough to include the weld metal and some parent metal) increases.

Dr. Mies also calls attention to the effect which differing relationships between general elongation and localized elongation in different materials in a tensile test may have upon corresponding behavior in a bending test. To illustrate this he cites the case of comparative tests carried out on samples of hard austenitic manganese steel and heat-treated chrome-nickel steel (Figs. 9 *a*, *b* and *c*) which gave the following results:

	Manganese Steel	Chrome-Nickel Steel
Bend Test		
Bending angle, degrees	180	160
Tetmayer's coefficient	80	60
Local elongation, per cent	82	200
Tensile Test		
Yield strength, kg./mm.^{2}	39	65
Ultimate strength, kg./mm.^{2}	123	155
Elongation, per cent in 10 cm.	60.5	8.4
Reduction in area, per cent	37.0	53.6
True maximum elongation, per cent	69	115

The manganese steel, which increases rapidly in strength with cold work, shows evenly distributed elonga-

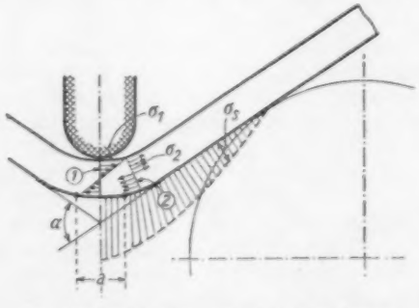


Fig. 8*a*—Bend Specimen with Rigid Center Section

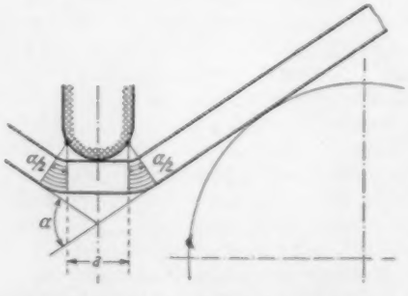


Fig. 8*b*—Bend Specimen with Rigid Center Section

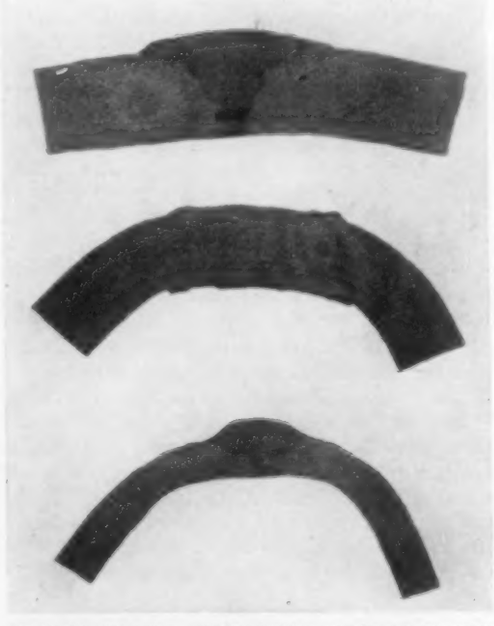


Fig. 8*c*—Bend Specimen with Rigid Weld. Bending Outside Weld

Figs. 8*a*, *b* and *c*—Effect of High Yield Point Weld Metal upon Behavior in Bending—Mies

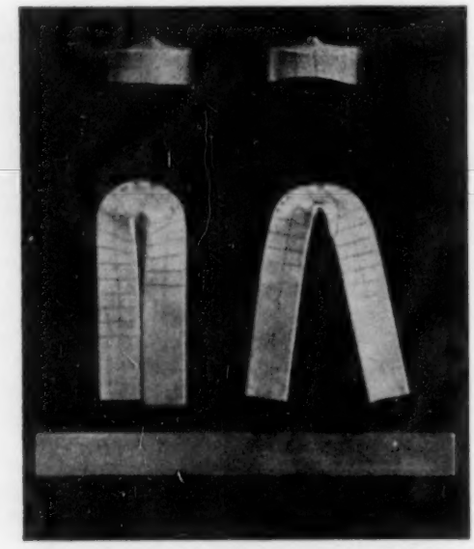


Fig. 9a—Bend Specimens. Left—Manganese Steel (Austenitic). Right—Chrome-Nickel Steel (Heat Treated). Below—Original Bar Form

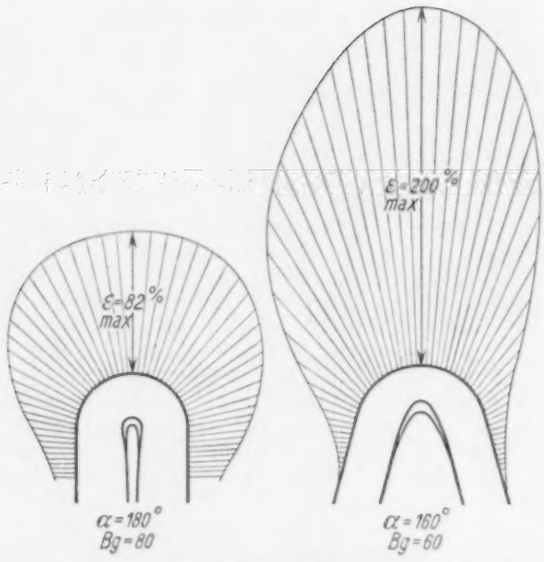


Fig. 9b—Distribution of Elongation in Outside Fiber of Bend Specimens of Fig. 9a. Left: Manganese Steel. Right: Chrome-Nickel Steel

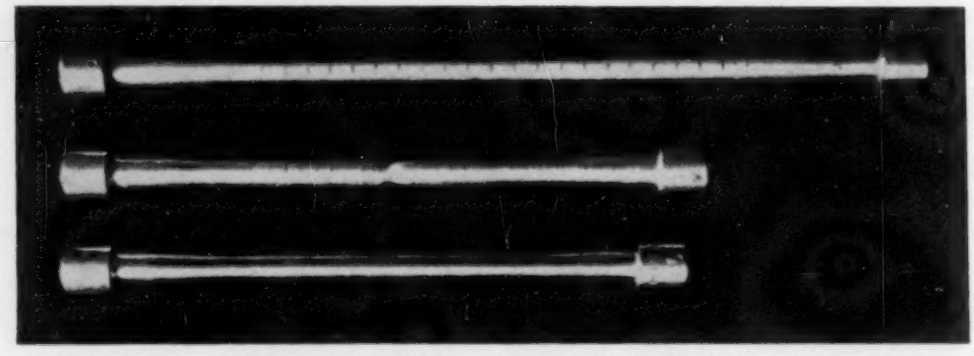


Fig. 9c—Tensile Specimen Corresponding to Fig. 9a. Above: Manganese Steel. Elongation 60.5%. Reduction of Area 37%. Center: Chrome-Nickel Steel. Elongation 8.4%. Reduction of Area 53.6%. Below Original Bar Form.

High Elongation as Contrasted to High Reduction of Area in Tension and Bending—Mies

tion over the entire length of the bar in a tensile test, with almost no localized necking. Localized necking, whether in the tensile test or at the apex of the bend in the bend test, is inhibited due to the fact that the increase in strength due to localized cold work overbalances the reduction in strength due to lessened area at any point of incipient necking. In the chrome-nickel steel, on the other hand, the effect of cold working upon the strength is proportionately much less and once necking has started at any one point there is a cumulative effect which causes the area to decrease rapidly so that the bar fails with a high percentage reduction in area but a relative low per cent over-all elongation. With these two steels it will be noticed that widely different conclusions as to comparative ductility would be reached depending upon whether the ductility was evaluated upon the basis of bend angle, of Tetmayer's coefficient or of the local elongation as measured along the tension face of the bend. These particular figures refer to unwelded bars but Dr. Mies suggests that somewhat similar variations may be expected in welds in which different types of base metal or different electrodes are used.

A conclusion which Dr. Mies draws from these results is that the bend angle or elongation percentage as measured in welds is likely to be to some extent a measure of the relative stiffnesses of weld metal and parent metal rather than a measure of their relative ductility, or of the skill of the welder. As an alternative he suggests the use of bars with a longitudinal weld, tested in bending or preferably in tension, in which the per cent elongation of the weld at appearance of first crack is used to measure the true ductility.

A number of other articles in the same series in *Die Elektroschweissung* in which Mies's paper appeared belong in the second or third of the classes listed and may also be of importance. Sexauer[27] shows that where the bend test is carried out by forcing the bend specimen down between two rolls through use of a plunger, the bending angle at first incipient crack is dependent upon the roll diameter used. For a given spacing between rolls the bending angle increases with increased roll diameter, but more rapidly for the thicker plate. Sexauer also shows a convenient adjustable apparatus for carrying out this test.

Zeyen[34] shows by a series of tests that for given bending roll diameter and given plunger thickness the bending angle at first crack will be greatly influenced by the roll spacing. Moser[33] gives diagrams (Fig. 10) showing the variation in per cent elongation from point to point along the face of the weld, due to the failure of the bar to bend in such a way as to fit itself accurately to the face of the round-ended plunger used. He suggests the use of a plunger end so curved as (empirically) to result in a circular curve in the specimen. In view particularly of the data given by Mies it is likely that this will be a more difficult task than Moser anticipates. E. Reuter[46] has made use of Moser's method in tests of samples from an electrically welded boiler drum. He used a plunger

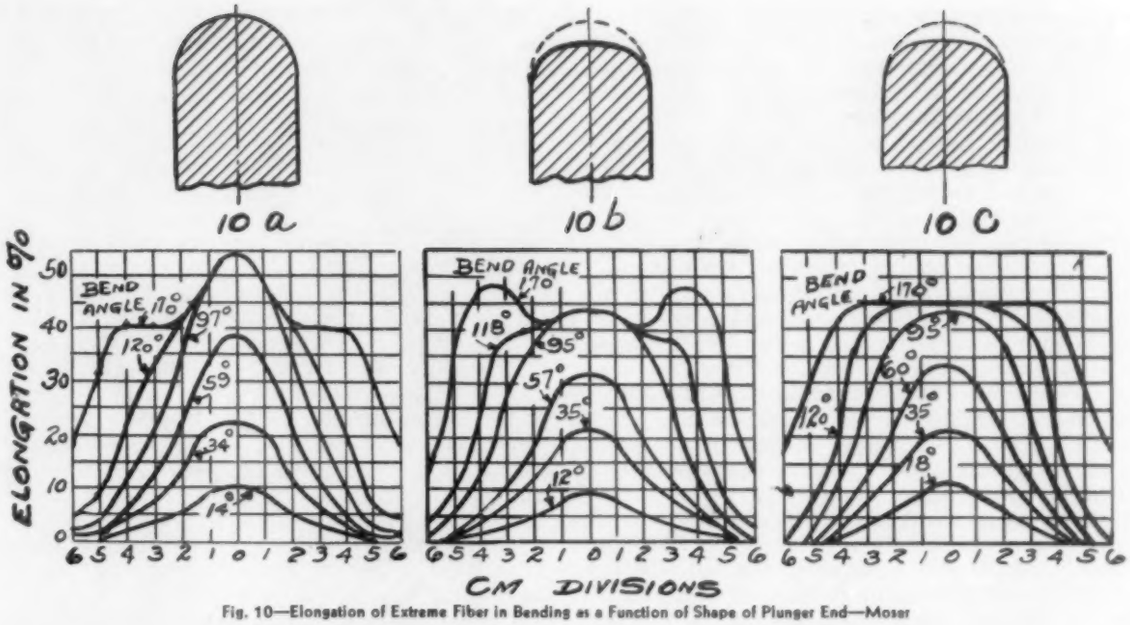


Fig. 10—Elongation of Extreme Fiber in Bending as a Function of Shape of Plunger End—Moser

head with a radius of 100 mm. over the central portion and radii of 50 mm. on each side, the total width being 120 mm. With this plunger, for bending angles ranging from 158° to 180°, the elongation over the central 30 mm. at the weld itself averaged 20.4% as compared to an average elongation of 21% over a full 200 mm. gage length.

Fiek[39] calls attention to the inaccuracy of Tetmayer's coefficient, due to probable shift in position of neutral axis and also to difficulty in measuring the radius of curvature of the bar. Surface elongation measurements give theoretically more satisfactory results but are experimentally difficult to make, particularly on short gage lengths. His feeling is that the bend test has in any event no scientific value so that it is best to keep it as simple as possible, using the bend angle as a measure of ductility, but standardizing the speed of the test and all dimensions of the test apparatus. He mentions that studies of a revised bend test method, apparently of the free bend type, were then under way in two German laboratories.

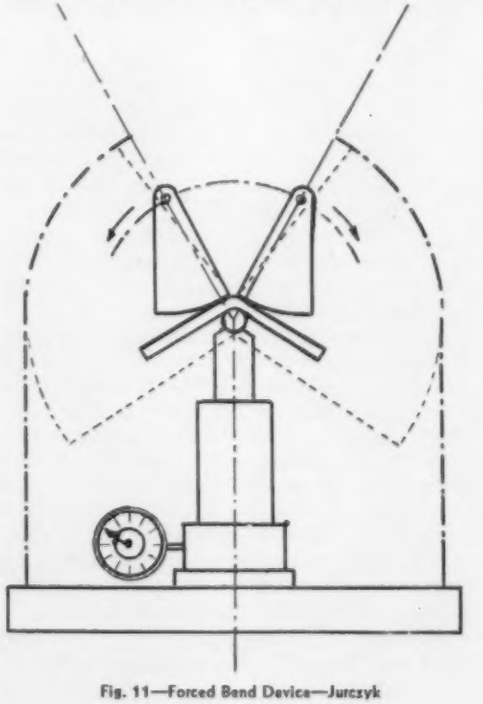


Fig. 11—Forced Bend Device—Jurczyk

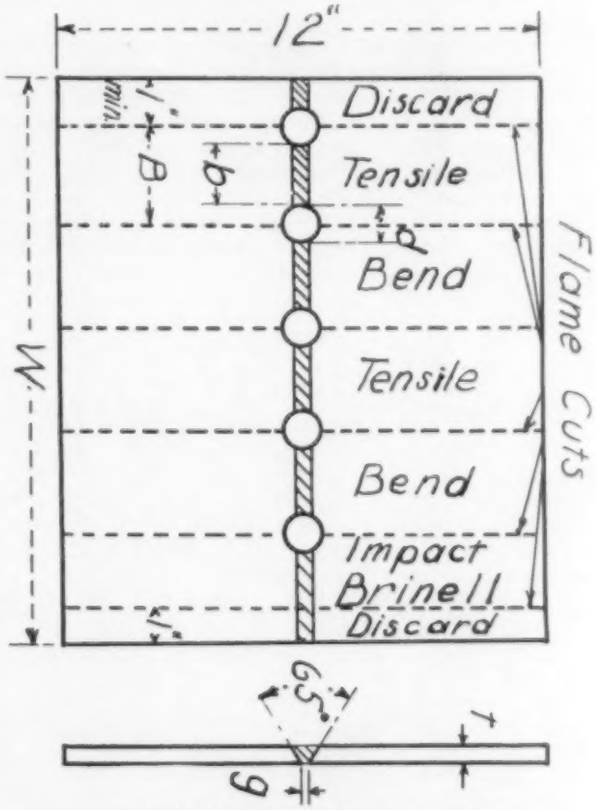


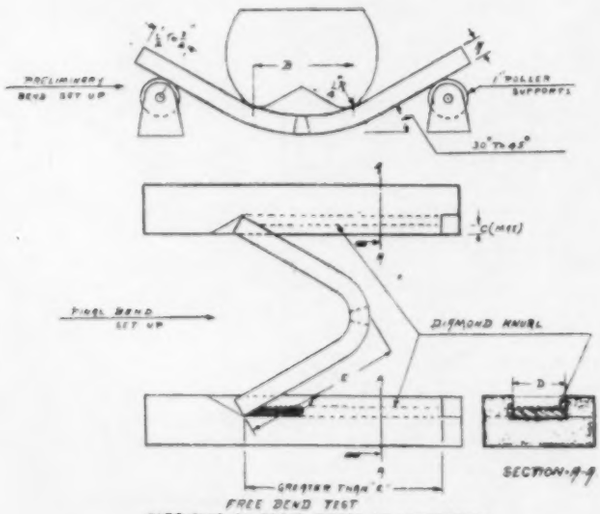
Fig. 12—Drilled Notch Flame Cut Bend Specimens—Roberts

t In.	B In.	b In.	d In.	g In.	W In.	$A = b \times t$ Sq. In.
1/4	1 1/4	3/4	1/2	1/16	12	0.1875
3/8	1 7/8	1 1/8	3/4	3/32	12	0.422
1/2	2 1/2	1 1/2	1	3/32	14	0.75
5/8	3 1/4	2	1 1/4	3/32	17	1.25
3/4	3	1 3/4	1 1/4	3/32	16	1.312
7/8	2 5/8	1 5/8	1 1/4	1/8	15	1.203
1	2 1/2	1 1/4	1 1/4	1/8	14	1.35

Jurczyk[31] recommends a radically different type of bend test in which by means of segmental rollers (Fig. 11) working each way from the center of the weld, the bar is forced to bend around a rigid pin. As an added feature Jurczyk recommends the use of hydraulic or other devices to measure the pressure upon the pin during this process. Other than a hypothetical ability to obtain a uniform radius of curvature over the entire length of the bend it is difficult to see what advantages would be gained by this modification in method of testing.

Daeves[30] gives probability curves for bending angle based on large numbers of tests of welded bars made from steels St. 37 and St. 52 and recommends the use of these probability curves to determine proper specification values for bending angle. He is somewhat skeptical as to the advantages of the higher ductility of the lower-nitrogen-content welds produced by means of covered electrodes or by means of gas rather than by arc, pointing out that certain American tests have indicated that these welds give lower endurance values.

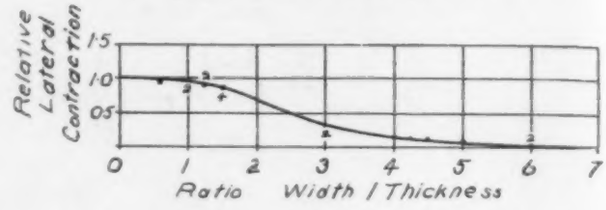
A. M. Roberts in an article in *Engineering*[41] recommends the use of a drilled notch specimen (Fig. 12) rather than a specimen with machined sides. In making up these specimens holes with a diameter equal to the thickness of the plate were drilled along the line of the weld, so spaced that the center lines of the holes came at the edges of the desired specimens. The successive bend and tensile specimens were then flame-cut apart. The advantage claimed by Roberts for this method is that the notch concentrated the whole deformation on the weld metal and the fusion zone between weld metal and the plate, so making it a much more severe test of the weld metal itself. From a practical standpoint this method also eliminated the necessity for machining the edges of the plate and also made it easy to insure that the bend be concentrated at the weld proper. Due to stress concentration resulting from the notch effect numerical values by this method are not strictly comparable with results from unnotched specimens unless a correction factor is employed. The German Federal Railway specifications[2] also call for a rounded notch in the specimen but in this case the radius of the notch is much greater (20 mm.) and so the notch effect is much less severe.



A	B	C	D
1/4" TO 1/2"	1 1/4"	1/4"	MAXIMUM WIDTH OF SPECIMEN PLUS 1/8"
1/2" TO 2"	2"	1/2"	
OVER 2"	3"	1/4"	

Fig. 13—Free Bend Test Adapters—Mapes and Howenstein

Fig. 14—Comparative Amount of Lateral Contraction in Specimens of Different Width-Thickness Ratios—Schuster
Small Figures Represent the Number of Specimens



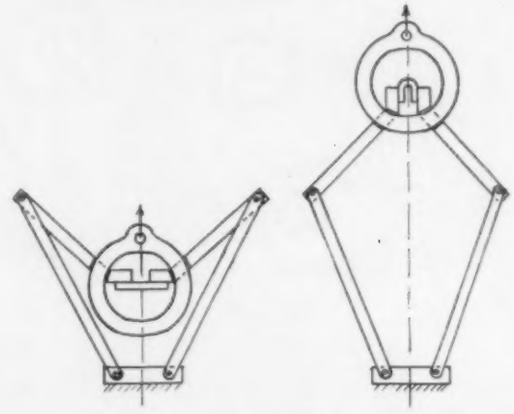


Fig. 15—Uniform Moment Free Bend Device—Block and Ellinghaus

The Scholer bend test machine on sale by the Baldwin Southwark Corporation differs from the German device principally in that segmental rollers of 6 in. radius, several times larger proportionately than the 50- or 100-mm. diameter rollers used in the German specifications, are used. The rollers are adjustable in position, the desired spacing between rollers being stated to be equal to the diameter of the plunger plus twice the thickness of the bar. This gives no clearance whatever between the rollers and the bar when the bar is bent double and seems of doubtful advisability as compared to the various foreign specifications which allow a clearance equal to the thickness of the bar.

Boetcher[42] and one or two other American writers have suggested the advisability of bending the bar edgewise with respect to the weld rather than crossways. In this way the entire cross section of the weld rather than face of the weld will be at the outside of the bend. All of the weld metal will be subjected to similar stress conditions, so giving a more satisfactory test result while the cost of preparation of the specimen is reduced due to the facts that a saw cut will give a sufficiently smooth surface for the edges and that no removal of the reinforcement will be necessary.

Two major objections to the American free bend test have been, first, the difficulty of insuring that the bend shall occur directly at the weld, and second, the danger that the bar during the later process of bending will fly out from the machine. Mapes and Howenstein[47] at the General Electric Company have recently developed devices for avoiding these difficulties, which are shown in Fig. 13. The fixture shown in the upper view aids in centralizing the initial third point bends (see Fig. 6) on the specimen, and in obtaining equal angles of bends at the two points. With this satisfactory initial start, future bending is almost certain to centralize itself, as desired. The knurled plates in the fixture in the lower view act to hold the specimen in place as the later bending is carried on.

An important paper presented by L. W. Schuster[45] before the Institution of Mechanical Engineers in March of this year discusses many phases of bend testing in detail. So far this has been available in this country in abstract form only. In this abstract emphasis is placed especially on the effect of the width-thickness ratio in a specimen upon bend test results. Schuster calls attention to the fact that the longitudinal plastic elongation at the outside of the bend must be accompanied by corresponding lateral plastic contraction in width and thickness, the volume of metal remaining virtually constant, and conversely for the plastic shortening at the inside of the bend. For a round or square specimen the lateral changes both in width and thickness are free to occur, and the resulting distortion is divided between the two. As the width of the specimen increases, the possible per cent changes in width of the tension and compression faces become more and more limited in amount, until for a very wide specimen the entire lateral distortion must take the form of a change in thickness. This calls for a more severe straining of the top layer and for specimens of given ductility, as the width-thickness ratio increases, results in a reduced angle of bend and reduced per cent elongation at instant of first crack. A curve given by Schuster (Fig. 14) based on experimental work, indicates that lateral contraction is virtually free for square specimens, and completely restrained for widths equal to $6t$ or more, with a transition zone between. This emphasizes the need for careful control of the width-thickness ratio, particularly for specimens within this range. For specimens with width 1.5 times the thickness, as called for in the A. S. M. E. Boiler Code Specification lateral contraction is very nearly free (85 to 90%). European specifications usually use proportionately wider specimens, and a given per cent elongation would correspond to a somewhat higher real ductility than with the American code.

Relative Advantages of Different Methods

The European plunger roller method has at the start a very clear-cut advantage as compared to the American free bend method, in that operation of the test is far simpler and more rapid. The specimen is cut to size, the edges smoothed off, then it is placed in the fixture and pressure applied until a crack occurs. It is then taken out, laid on a table and angle of bend measured in more or less automatic manner. No gage marks on the specimen are needed, there is no fine measuring to be done, and the bending itself is carried out in one rather than two steps. Within certain set limitations, the angle of bend furthermore seems to give an accurate measure of the properties desired.

These limitations, however, are rather important in scope. Sexauer, Zeyen and others have brought out very clearly that comparable results between different laboratories as to angle of bend are possible only if the plunger roller apparatus is rigidly standardized as to thickness of plunger, diameter of rollers and spacing between rollers. What seems to have been tacitly understood rather than emphasized is the fact that these same tests also imply that values of angle of bend will be comparable as between different thicknesses of plate only if all dimensions of the plunger roller apparatus are caused to vary in direct proportion to the plate thickness. European specifications in general, as indicated in Table 1, avoid this difficulty by calling for tests on plate of 10 mm. thickness only, and specifying all necessary dimensions as based on that thickness. Except in the British Specifications,[11] other thicknesses are not provided for.

Another difficulty, as brought out particularly by Mies, is the fact that distribution of elongation as between weld metal and parent metal may be more important than total angle of bend. With weld metal of high yield point, virtually all the distortion may be forced into the adjacent parent metal, giving possibly a high total angle of bend irrespective of whether the weld metal is of high or low ductility. For research purposes, the desirable method would be to scribe a number of gage lines on the specimen and measure the distribution of elongation over the weld and adjacent metal in this way. Results of measurement of this kind are given in several of the papers listed. As a commercial matter, measurements of elongation taken from gage marks within the weld metal, as called for in the free bend method, would seem to be sufficient. The attitude in several of the European papers listed is to recognize this fact, but to recommend continuance of the use of the bending angle method, because of practical difficulty in measuring elongations over the resulting short gage lengths.

A more important fundamental difficulty with the plunger roller method does not seem to have been mentioned. In the plunger roller method, the plunger must have an appreciable thickness, and it is usually specified to be $2t$. The minimum center line radius of curvature of the bend is therefore $1.5t$. Up to 90° to 100° angle of bend, tests seem to show that the per cent elongation in the most heavily strained metal on the tension side of the bend is approximately proportional to the angle of bend. Further bending beyond this operates to extend the bend over a greater length of bar, but not to increase the per cent elongation at the points already bent. With welding methods of a few years ago, bending in this manner was amply sufficient to develop the full ductility of the weld. At present, welded bars frequently can be bent almost or quite flat upon themselves before failure occurs. The plunger roller method obviously is inadequate to handle welded bars of this high ductility.

An objection to both the free bend and the plunger roller methods is the fact that in both the bar is under a complex stress condition, bending of varying intensity along the length of the bar, coupled with shear or compression. The compressive load component when computed quantitatively will usually turn out to be of less importance than would be expected (unit stress due to compressive component not over 10 to 15% of the maximum extreme fiber bending stress), but the amount will vary depending upon the size of bar and the method of testing. The ideal method would be to test under uniform conditions, with the percentage effect of compression and shear *vs.* bending moment the same for all bars and with bending moment uniform at least over the weld and a short distance each side. Application of a pure uniform bending moment over the central section of the bar, as in the case of a simple beam with third point loading, would be one way this could be done.

Block and Ellinghaus[40] have developed a device by which this can be done, so obtaining a true "uniform bending moment" device, as shown in Fig. 15. A simplified form of the Block and Ellinghaus device has been developed and used for a few tests in Schenectady. For research work, as for instance where comparative strength and ductility of weld and parent metal are to be obtained, and per cent elongations are to be made separately over the two, this uniform bending moment quality would be highly desirable. The practical difficulties connected with clamping the specimen in proper position in this device could probably be readily overcome. The same fundamental difficulty however remains as in the plunger roller device. Due to clearance limitations the bar cannot be bent to a radius much smaller than $1.5t$ in any uniform moment device, so that any bar with a high ductility would have to be bent first as far as possible in this

device and then finished by the free bend method. This difficulty seemed to us to rule the device out for other than research problems, and it was not repaired after one arm had been accidentally broken.

The one real objection raised in English or European articles to the American free bend method, and this objection was raised several times, was the difficulty of obtaining accurate measurements of elongation over the short gage lengths used. Measurements of elongation were either openly or tacitly treated as theoretically more desirable than angle of bend, but as being impracticable for other than research work. From this pessimistic attitude there easily followed in some cases the further conclusion that the bend test should be treated as primarily a work shop test semi-quantitative only in character. This conclusion is rather negatived from a research standpoint by the extensive information presented by Mies. Whether it is true from production control or acceptance test viewpoints is primarily dependent upon the practicability of the elongation measurements. Results in America with these have been relatively satisfactory using flexible scales, but there is room for the development of a caliper or micrometer which will give still better results. This would necessarily involve some form of correction for difference between arc and chord on the bent bar, but this should not be impossible.

The recent paper before the Institution of Mechanical Engineers by Schuster[45] emphasizes the need of careful control of width-thickness ratio in bend testing. The Boiler Code specifies a ratio of 1.5, but it is possible that this is not always adhered to. The A. S. T. M. bend testing specifications call for a ratio of 3 to 1, and it might be wise to consider changes to bring the two into concordance.

Bibliography

Specifications

[1] "Specifications for Welded Steel Structures," *German Industry Standard (DIN)*, 4100, 2nd Edition, July 1933.

[2] "Tentative Technical Delivery Conditions for Welding Wire for Joint and Built-up Welds on Standardized Types of Steel, Using Gas and Arc Welding Methods," German Federal Railways Company.

[3] "Materials Testing Methods," *German Industry Standards (DIN)*, 1605, June 1924.

[4] "Specifications for Delivery and Acceptance of Depositing Materials for Gas and Arc Welds," February 1932 Edition. *Die Elektroschweissung*, vol. 3, no. 3, March 1932, pp. 54–56.

[5] "Specifications for Welding Electrodes for French Naval Construction," *Chambre Syndicale des Constructeurs de Navires et de Machines Marines*, 1933.

[6] "Specifications for Stationary Structures. Technical Specifications for Metallic Frameworks and Floors," *Le Bureau Veritas*, Paris, France, 1934.

[7] "Rules for Construction and Classification of Steel Ships. Chapter 9. Electric Welding," *Le Bureau Veritas*, 1934.

[8] "The Hungarian Specifications for Welded Steel High Buildings." Bela Enyedi, *Die Elektroschweissung*, vol. 5, no. 11, Nov. 1934, pp. 211–212.

[9] "Unification of Methods and Specifications for Testing Metallic Materials. Bulletin No. 6 of *L'Industria Meccanica* (Italy), 1934, No. XII, September 30, 1934.

[10] "Polish Code for Welded Steel Structures," *Die Elektroschweissung*, vol. 5, no. 2, February 1934, pp. 35–36, and Am. Welding Soc. Journal, vol. 13, no. 7, July 1934, pp. 12–15.

[11] "British Standard Specification for Metal Arc Welding as Applied to Steel Structures," *British Standards Institution*, No. 538 (1934).

[12] Metropolitan-Vickers Specification.

[13] "Standards Association of Australia Code for Metallic Arc Welding in Steel Buildings," Code No. CA 8 (1933).

[14] "Tentative Method of Bend Testing for Ductility of Metals," American Society for Testing Materials, Tentative Specification E16-31T.

[15] "Rules for the Fusion Process of Welding in Rules for Construction of Unfired Pressure Vessels," Section VIII, A. S. M. E. Boiler Construction Code, 1932.

[16] Richard Hoffman, "Specification for Welded Steel Structures in Czechoslovakia," *Die Elektroschweissung*, vol. 4, no. 9, Sept. 1933, p. 171.

Bend Testing

[17] W. B. Miller, "Bend Test as Applied to Welded Coupons," Am. Welding Soc. Journal, vol. 6, Sept. 1927, pp. 133–140.; *Acetylene Jour.*, **29**, Oct. 1927; Am. Welding Soc. Journal, **24**, 358, 1927. Description of results of tests, using the old Am. Welding Soc. plunger and ram method.

[18] A. B. Kinzel, "A Critical Study of the Bend Test as Applied to Iron and Steel," *Trans. Am. Soc. for Steel Treating*, Nov. 1927, pp. 778–793, and p. 826.

[19] W. B. Miller, "The Bending Test for Welded Specimens," Am. Welding Soc. Journal, **25**, 13–16 (1928). Suggests measuring elongation of the outside fibers either by drawing a circle to coincide with the outside curvature and applying the formula: Elongation = $100t/2R$, where t = thickness of specimen and R = radius of curvature; or by establishing gage marks before bending and measuring the actual elongation directly.

[20] S. W. Miller, "Allowable Stresses in Welded Structures," Am. Welding Soc. Journal, vol. 7, Sept. 1928, pp. 21–27. Recommends free bend test and Kinzel's formula, $S = (T/7.15) \times (E/10)$, where S is the permissible working fiber stress, T the ultimate tensile strength and E the percentage elongation as determined by a bend test.

[21] Anon. "The Bend Test." *Metallurgist* (Supp. to *Engineer*) Oct. 26, 1928, pp. 146–147. Discussion of different types of bending tests, their advantages and disadvantages.

[22] W. Zimm, "Testing of Welded Joints," *Veroeffentlichungen des Zentral-Verbandes der Preussischen Dampfkessel-Ueber-wachungs-Vereine*, no. 5, 1929, pp. 17–22, and *Waerme*, vol. 52, no. 30, July 27, 1929, pp. 575–580. Extension of bending tests by application of ball indentation test is recommended.

[23] F. G. Tatnall, "How to Test Welds," Am. Welding Soc. Journal, vol. 8, no. 9, Sept. 1929, pp. 152–159 and (discussion), no. 11, Nov. 1929, pp. 21–30. Tests in tension and free bending and studies of stress distribution are recommended. Methods and equipment are described.

[24] H. Kemper, "Critical Considerations of the Testing of Weld Seams," *Autogene Metallbearbeitung*, **23**, 199–205, 218–226, 234–241, 253–258 (1930). Tests are divided into two categories—destructive and non-destructive. Application and operation of each test is fully discussed.

[25] W. B. Miller, "Bend Tests," Am. Welding Soc. Journal, vol. 9, no. 10, Oct. 1930, pp. 75–78. Recommends that bend test for welds be evaluated by measuring per cent elongation of outside fibers, rather than angle of bend.

[26] M. Füchsel, "Adaptability of Bending Test for Testing of Welds," *Die Elektroschweissung*, no. 6, June 1930, pp. 108–110. Method of carrying out bending test.

[27] Sexauer, "Influence of Bending-Roll Diameter," *Die Elektroschweissung*, vol. 2, no. 4, April 1931, pp. 73–74. On basis of tests the influence of diameter of rolls on test results is shown.

[28] O. Mies, "Bending Tests with Welds," *Die Elektroschweissung*, vol. 2, no. 9, Sept. 1931, pp. 170–176. A thorough theoretical study of behavior in bending for welded and unwelded specimens.

[29] Anon., "Report of Committee on Standard Tests for Welds," Am. Welding Soc. Journal, vol. 10, no. 11 and 12, Nov. 1931, pp. 14–40 and Dec., pp. 38–50. Standardized procedures for various mechanical tests (tests of base metal, weld metal, sample welds, etc.).

[30] K. Daeves, "Physical Properties of Arc-Welded Joints," *Die Elektroschweissung*, vol. 2, no. 7, July 1931, pp. 121–126. Influence of form of weld on strength; strength values and bending angles in relation to thickness of plate; frequency of bending angle, fatigue strength of welds, etc.

[31] K. Jurczyk, "Critical Evaluation of the Bend Test for Welded Test-Pieces, *Die Elektroschweisssung*, vol. 3, 1932, pp. 154–155. Describes an apparatus in which the welded test-piece is bent around a pin in such a way that the deformation must be the same for weld, transition and parent metal.

[32] C. v. Roessler, "The Measurement of Elongation in Bending Tests," *Schmelzschweissung*, **11**, 242, (1932). An apparatus for measuring the radius of curvature of bent sheet metal is described.

[33] M. Moser, "Obtaining a Steady Curvature in Technical Bending Tests," *Stahl und Eisen*, **52**, 409–411 (1932). Recommends that the mandrel about which the specimen is bent should not be semi-cylindrical, but should have a definitely flattened surface, so that the specimen is bent into a circular form when the bending angle is large. If this angle exceeds 170–180°, an additional apparatus in the form of a hollow wedge is used so as to avoid local necking.

[34] K. L. Zeyen, "Influence of the Diameter of Bending Rolls and Their Distance Apart on the Results of the Bend Test of Welded Specimens," *Stahl und Eisen*, **52**, 879–880 (Sept. 8, 1932). Effect of different diameters on the angle of bend is not very marked. Effect of spacing the rolls at distances of 30, 50 and 70 mm. was then tried; with the wider spacing, it was always possible to get an angle of bend of 180°.

[35] H. Buchholz, "Notes Concerning the Testing of Welded Specimens in Tension and Bending," *Schmelzschweissung*, vol. 11, no. 7, July 1932, pp. 147–53. Effect of method of preparing specimen for tensile and bending tests of V-shaped oxyacetylene welds.

[36] A. C. Vivian, "Percentage Elongation," *Welder*, vol. 4, Nov. 1932, pp. 1–7. Test methods and test results which have a bearing on the behavior of welded steels.

[37] "Plunger-Roller Bend Test Device as Developed by Prof. C. H. Scholer," Kansas State Agricultural College, Manhattan, Kansas. *Instruments*, **1933**, 6, p. 64; also *Baldwin-Southwark Corporation Bulletin* **46**, May 1933.

[38] C. T. Schwarze, "Internal Stresses in Welds," Am. Welding Soc. Journal, **12**, 23–25 (1933). A bend-testing apparatus is described, having rocker bearings which move with the specimen so as to eliminate secondary stresses as far as possible.

[39] G. Fiek, "Test Methods for Welds (Tentative Standardization)," *VDI Zeitschrift*, **77**, 1005–1008 (1933). Review of recent work of the Technical Committee for Welding Technique of the VDI covering mechanical testing, stress measurements, X- and Gamma-ray investigations and electrical and acoustic tests.

[40] E. Block and H. Ellinghaus, "The Free Bend Test (New Device"), *Die Elektroschweissung*, vol. 4, no. 7, July 1933, pp. 126–129. Description of a device by means of which approximately uniform bending moment over the weld and adjacent metal may be obtained.

[41] A. M. Roberts, "Simple Tests for Arc-Welded Joints," *Engineering*, vol. 137, no. 3551, Feb. 2, 1934, pp. 112–116. Discussion of drilled-notch form of tensile and bend test specimens. Cost and time of machining drilled-notch specimens is less than one-tenth of that of other forms of specimens investigated.

[43] H. N. Boetcher, "Bending Tests of Welds," Am. Welding Soc. Journal, vol. 13, no. 2, Feb. 1934, pp. 31–32. Sideway bending of specimens in such way that entire cross section of weld is at outside of bend.

[42] G. Fiek and A. Matting, "The Adaptability of the Folding Test for the Examination of Welded Joints," *Autogene Metallbearbeitung*, vol. 27, no. 8, April 15, 1934, pp. 115–121. Suitability of bending tests for testing welds.

[44] G. Fiek, "Test Methods for Welds," *Die Elektroschweissung*, vol. 5, no. 4, April 1934, pp. 67–71. Testing methods for welds; testing of strength and mechanical-metallurgical characteristics.

[45] L. W. Schuster, "The Bend Test and Its Value as a Guide to Ductility," *The Engineer*, vol. 159, no. 4134, April 5, 1935, pp. 354–356 and (discussion), pp. 360–361. Institution of Mechanical Engineers Proceedings, vol. 129 (1935)pp. 251–398.

[46] E. Rueter, "Strength of Test Specimens from an Electrically Welded Drum," *VDI Zeitschrift*, vol. 77, Aug. 26, 1933, p. 917. Results of notched-bar tests, shearing tests and cold bending tests. Modified form of plunger roller method used, with specially shaped plunger end.

[47] F. S. Mapes and F. Howenstein, "Free Bend Tests on Welds," Am. Welding Soc. Journal, **13**, 28 (Oct. 1934). Describes new fixtures, developed at General Electric Co., to obtain symmetrical shape in making initial bends at third points, and to hold the bar in place in the testing machine while completing the bending operation. Danger of accident is eliminated and bends are centered on the weld itself.

Prediction of Weld Performance*

By NAIRNE F. WARD, M.M.E.†

THE first part of this discussion is a consideration of the general factors which influence the performance of welds. The second part describes the use of models of welded construction in the formulation and verification of design data.

Part I

It is possible to predict weld performance if all the factors are known that enter the welding process to such a degree that results are duplicated. Much has been said on this score under the general subject of procedure control. Much has been done about controlling those conditions that affect the quality of welds, especially in the aircraft industry. Utilization of procedure control in this industry has produced surprising duplication of performance. In fact, this may be considered routine success where welding is now used in aircraft construction.

Innumerable tests have been made on welds deposited under procedure control as proposed by the AMERICAN WELDING SOCIETY. Tensile tests of specimens welded in widely scattered localities have been duplicated within 5% of ultimate strengths and comparable values of ductility.[1]

The aircraft industry has been forced by necessity to maintain highest standards of quality. Close control of the welding process is axiomatic and requires an intimate study of all factors that enter weld deposition. The principal difficulties surrounding welding may be attributed to the light gage metals and complex joints that are predominantly used in aircraft. One instance is shown in Fig. 1 (Frontispiece). The sensitivity of these metals to welding heats requires accurate control. All these preventive precautions must be exercised to forestall failure. It is indispensable that all failures be prevented. Even one failure in ten thousand welds cannot be allowed, while in other types of construction one failure in 10,000, if it should occur, can be adequately covered by the usual warranty of the manufacturer to "repair and replace parts which fail due to defective material or workmanship." In the latter instance there may be but little at stake in the present development of welding. But the aircraft structure must be 100% reliable, if confidence in the safety of air travel is to be ultimately attained.

Much information is available with which to eliminate the possibility of failure. Such guidance as revealed by appropriate tests, when properly interpreted, prevent much of the concurrent expense often so prevalent with slipshod or "cut and try" methods. These are attempts to indicate a better procedure for the production of sound welds.

Briefly, these tests are: Hardness, strength, ductility, impact, fatigue, microscopic, magnetic, acoustic, or X- and gamma-radiography. Lacking sufficient correlation of the data from these tests, conclusive evidence is dependent upon correct interpretation. These tests are none too few for producing information that constitutes a basis for duplicating quality welds. For instance, the meaning of shadows or density variation in X-ray films is only known after exploration by microscopic examination and chipping, if the cause of this condition is to be found. Porosity, if present, is easily detected. But with modern control of deposit by flux-coated rods and chemistry of filler metal, porosity is less of a problem than formerly. Films improperly exposed, focused or developed are worthless. Radiographs by experienced operators and interpreted by trained analysts are indicative of actual conditions in welds. These are preventive techniques like preventive medicine which lessen possibility of sick welds.

Ingredients of Sound Welds.—Any prediction must necessarily be based upon what goes into the weld. The result of the absence of any of the following requirements for good welding procedure is a product inferior to a sound weld, namely:

1. Welders with thorough training supplemented by careful inspection;

2. Materials of proper quality to be checked upon receipt;

3. Proper design.

Concerning the first and second criteria for deposition of sound welds, practice has fully demonstrated their value. The third has received only part of the attention it deserves. Many welders have met their supreme tests on designs that were the "carry-over" of riveting practice with excessive weights and accompanying difficulties for adjustment of thermal stresses, or of ideas that never should have been in welded structures. Perhaps the welder has been judged more unfairly due to the misapplication of design than to any other cause.

What is more important than welding-conscious designers and engineers? This interest must be engendered if not acquired where these men specify welding. Untrained judgment usually results in dissatisfied customers and lawsuits. Excellent training in design is available at the better universities, trade schools and welding clinics of welding equipment companies.

A more detailed outline of the factors that cause variation of properties in the weld and its vicinity is of interest here, because the evaluation of the elements in the process that are controllable is required in the specification of welding. The accuracy with which performance of a weld can be predicted depends upon the degree of control exercised during deposition of the weld. Some vitiating effects due to the application of heat obviously are inherent in the process. Yet moderate use of heat in the flame or arc can be utilized in adjusting or compensating for these effects. Lacking means of alleviating the vitiating effects uniformly, heat treatment of the structure is the best procedure. An inventory of the factors that produce the greatest changes in welded construction, may be summarized as below:[2]

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* Abridged from paper before San Francisco Section, AMERICAN WELDING SOCIETY, May 24, 1935.

† Assistant Professor, Mechanical Engineering, University of California; Visiting Lecturer in Metallurgy and Welding, Boeing School of Aeronautics.

[1] J. B. Johnson, "Development of Oxyacetylene Welding in Aircraft Industry," *Western Machinery and Steel World*, October 1931. N. F. Ward, "Reliability of Aircraft Welds," Preprint A. S. M. E. Aeronautics Meeting June 1934.

[2] For more detailed treatment of this subject consult pp. 248–255 and pp. 270–275, *Airplane Construction and Repair*, McGraw-Hill Book Co.

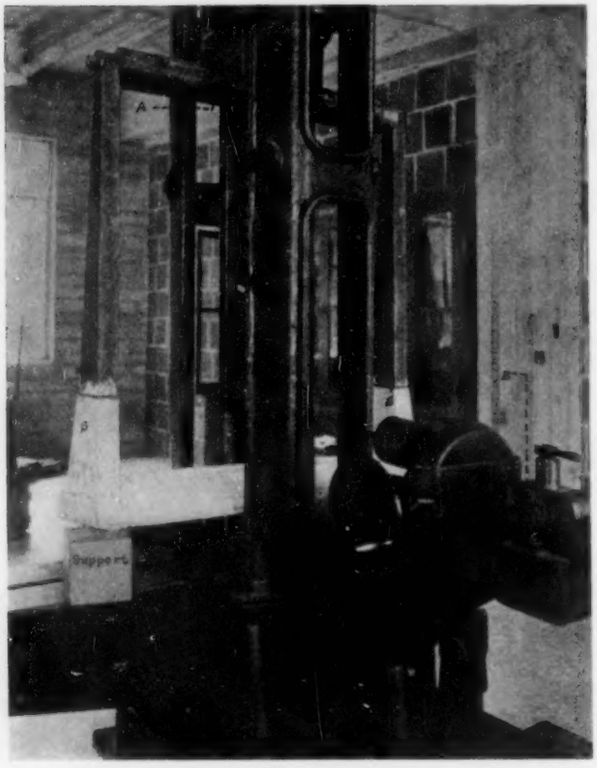


Fig. 2

I. Judgment of Welder and User
- (*a*) Physical abuse—overloading
- (*b*) Reliable inspection knowledge—detection of conditions contributing to failure
- (*c*) Application of correct welding procedure

II. Application of Heat
- (*a*) Amount of heat such as regulation of current and voltage or gas pressures
- (*b*) Position of flame or arc
- (*c*) Penetration—depth and contour of fusion zone
- (*d*) Bead proportions
- (*e*) Adjustment of thermal stresses
- (*f*) Heat treatment

III. Alteration of Rod and Base Metals
- (*a*) Degree of contamination—cold shuts, gaseous and solid
- (*b*) Quality of metal as received—variations due to metallurgical or mechanical condition
- (*c*) Corrosion

IV. Design Considerations
- (*a*) Change of section by proper filler welds
- (*b*) Symmetry of welds—usually welded from one side for economy in thin metals up to $^1/_2$ in.
- (*c*) Provision for thermal stresses—sequence of welding and allowance for residual stresses
- (*d*) Nature of application—structural with static or dynamic loading, at elevated temperature or low temperature

Demonstration of the relative importance of each consideration above was given by a large selection of suitable illustrations, and rubber models of weld specimens, to show the effect of advantageous alterations in design for welding.

Part II

The usual tests on specimens are limited to the prediction of these welds when deposited under similar conditions. Welds, when incorporated in a complex structure, generally develop widely different characteristics. For these conditions, reliable forecasting of the performance can be made more accurately from survey of physical properties in the completed unit, or, if impossible because of size, in a model of the full-sized structure. When such a survey is made on units assembled by known procedures, prediction on similar structures enable formulation and checking of design data. For example, when single weld specimens or coupons develop properties within specified ranges for that material and there is a failure in the welded structure, the model test reveals the weaknesses in a given design, such as faulty welding procedure, improper adjustment of thermal stresses, etc. Essential modifications in design to withstand service conditions are indicated by proper analysis, according to the principles outlined in the following discussion.

What Is a Model?—In other words, a more reliable analysis is facilitated by the use of a complete unit of smaller dimensions than the full-sized structure, known as the prototype. The model duplicates in every dimension the geometrical similarity of the prototype. The essential requirement for geometrical similarity is that the ratios of all corresponding dimensions remain constant, which exists when similar structures are stressed below the proportional limit of the material. This condition is satisfactory in so far as the induced stresses do not produce permanent deformation or variable ratios of similar dimensions.

When model and prototype are tested dynamically, results are only of value when dynamical similarity exists. To be dynamically similar requires not only constant ratios of forces, velocities and accelerations, but relations between these ratios and geometrical constants that are dynamically correct under the predominant physical reactions of the prototype and its model.

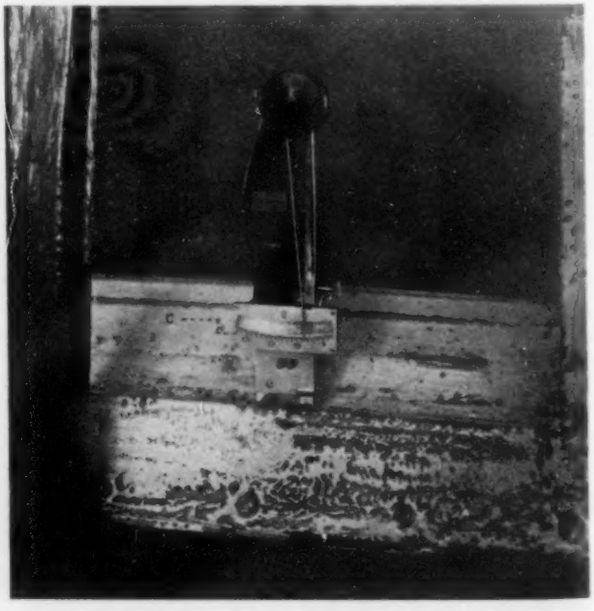


Fig. 3—Dark Areas Due to Traces of Oil in Coating

Requirements of a Model.—The use of models is not new. It has extensive utility in the prediction of performance in hydraulic and aerodynamic structures, such as dams, airfoils and wing sections. These models are miniatures of the large-sized structures composed of similar materials. Where different materials are used, corrections are made for density variation.

Celluloid or bakelite sections when strained under polarized light have been used for photoelastic characteristics of welded joints. Similar studies with rubber are useful where the section under investigation is representative of the prototype. The manipulation of these substances in a complex structure has serious limitations because so much depends upon the selection of a truly representative section. Cementing of bakelite or celluloid and instability of rubber joints introduce serious difficulties when it is necessary to evaluate their effects in terms of welded steel construction. For upon these evaluations must depend the predicting of performance of the prototype.

The direct solution of the physical response to load concentrations in complex welded structures lies in a model of welded steel or whatever material is used in the model. The results are then directly comparable, so long as the law of similitude is valid.

Designing aids that are gained from models may be summarized as follows:

1. Solution of stresses resulting from unknown distribution of load;
2. Determination of kind and magnitude of stress concentrations;
3. Formulation of design data. Effect of alteration evident in the model;
4. Verification of design data;
5. Facility in handling tests—small model size requires only small size of test equipment.

A particular problem may be outlined involving the correct design of road building equipment,[1] by means of two series of tests. The first series of tests was used to evaluate the stress concentrations in this model under the most severe condition of loading, i.e., loads in excess of tractor draw-bar pull concentrated at the middle of the cutting blade, the survey of stress being made with a sensitive extensometer while under load. The second tests were used to determine the torsional stiffness in a welded model of a bulldozer.

By means of the following relations, in addition to procedure control, prediction of performance of this unit was verified by rigorous service tests on the full-sized bulldozer, redesigned in conformity with physical indications of the model. The result was that the savings in manufacturing cost and maintenance effected by applying the model's predictions satisfied customers here and abroad.

For interpretation of results at relatively low velocities and accelerations encountered in this service, it is only necessary to know the moduli of elasticity for the steel in the large unit and the model. Then from the following relations it is possible to predict the maximum stress and its location in the large unit by a series of strain readings within the proportional limit of the steels used:

Let n = scale factor

$$\text{then } n = \frac{\text{lineal dimension of prototype}}{\text{lineal dimension of model}} \tag{1}$$

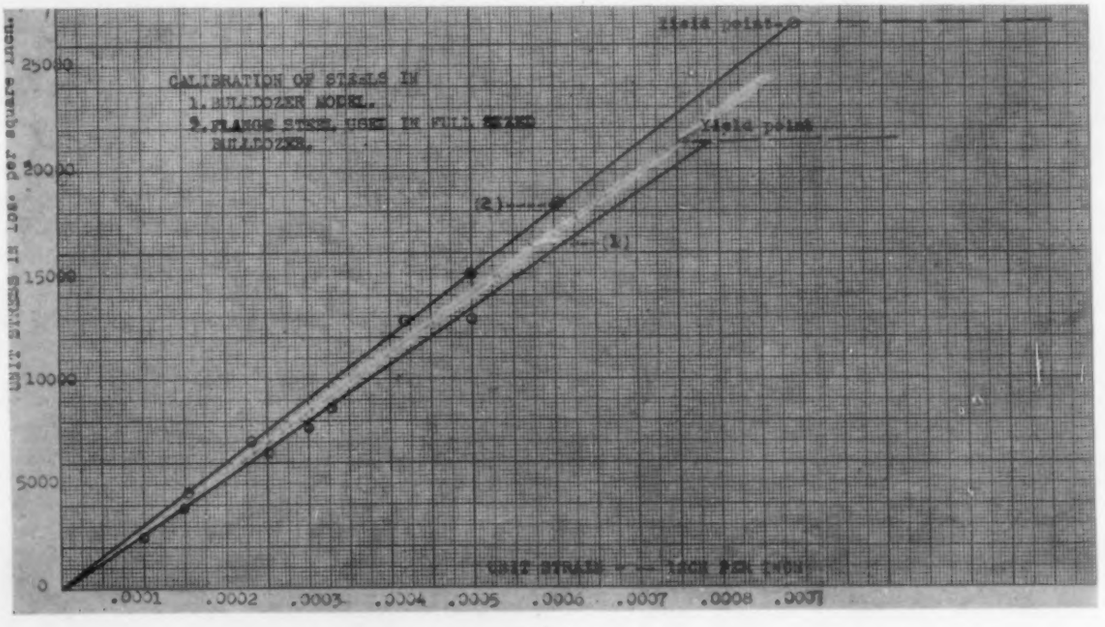


Fig. 4

For quantities involving areas such as stress

$$m = \frac{\text{stress of prototype}}{\text{stress of model}} \tag{2}$$

$$\text{Area} = (\text{lineal dimension})^2 = n^2$$

therefore, the relation of Force in prototype/Force of model

$$= m \frac{E_p \times p \text{ of prototype}}{E_m \times m \text{ of model}} \tag{3}$$

or: Stress in prototype/Stress in model $= n^2 \times \dfrac{E_p \times n}{E_m \times p}$,

where E = modulus of elasticity and p = density.

Description of Tests, Series 1

Load readings on the model were recorded as taken from the beam scale on the Universal Testing Machine

[1] This investigation was done in the capacity of a consultant. All details of construction have been patented by the retaining company, whose permission has been granted for publication.

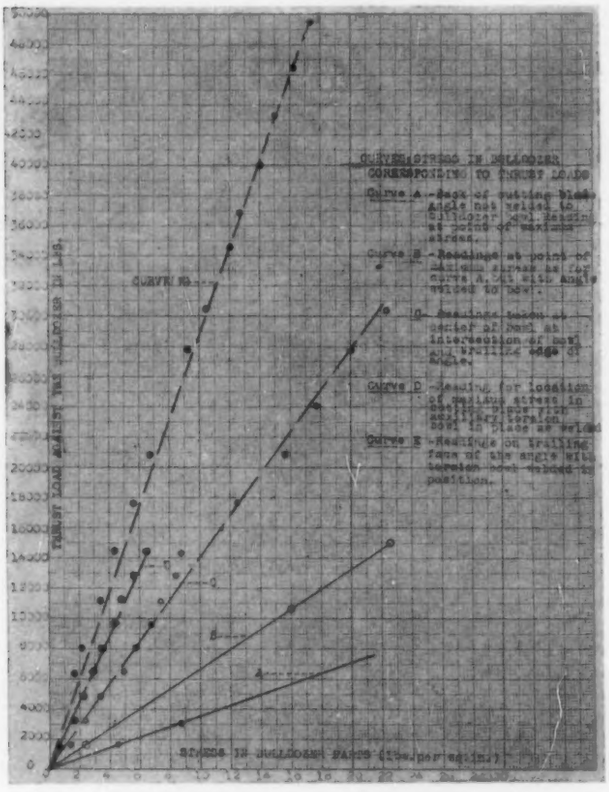


Fig. 5

(*B*—Fig. 2), and the amount of strain at the surface of the bulldozer was recorded from the readings obtained by means of a Huggenberger Tensometer, shown at *C*—Fig. 3. All readings of load were taken within the yield-point strength of the material used in the model.

In order to obtain the physical properties of the material of which the bulldozer model was constructed, standard flat tension test specimens were loaded and the strain readings recorded on a Ewing Extensometer. The values of unit stress and unit strain were plotted as Curve 1 (Fig. 4). Curve 2 on this same sheet is plotted for the material used in the full-sized bulldozer. These curves will later be interpreted in terms of this model test.

Readings during Tests

Preliminary readings of the Huggenberger tensometer were taken to locate the approximate point of stress concentration of maximum intensity in the back side of the bowl with the angle and side sockets (*S*, Fig. 2) only tack-welded in position. Subsequent readings on the bulldozer model were taken on the back side of the blade, the top side of angle, the central portion of the bowl and at the top edges of the bowl at the intersection of the two respective sockets. (See Fig. 7.)

Discussion of Results of Tests, Series 1

Test readings on the back of the bowl under the blade showed localization of stress of high intensities in tests. For this reason the angle was completely welded to the back side of the bowl before proceeding with further tests.

The values of stress when plotted against values of load shown in Curve *C*, Fig. 5, for stress values of the material in the bowl back of the blade was exceeded when equivalent load of 30,000 lb. was reached. This value of stress was not modified by any subsequent adjustments in design. The only method of improving the strength along this back edge is to insert backing-up plates equally spaced between the blade bolts. While this load imposed on the bulldozer blade is fully twice that exerted by the tractor before the engine stalls, investigation showed that the construction would be safe for steady load.

Regarding tests on the angle it was impossible to exceed the elastic limit of the angle material with loads totaling as much as 15,000 pounds, as will be seen by consulting curve *D*, Fig. 5.

A modification in design, as discussed in test Series 2, below, was found from plotting loads against stress in the angle to actually increase in strength and stiffness, as will be noted by referring to Curve *E*, Fig. 5. Loads on the angle as much as 50,000 pounds per square

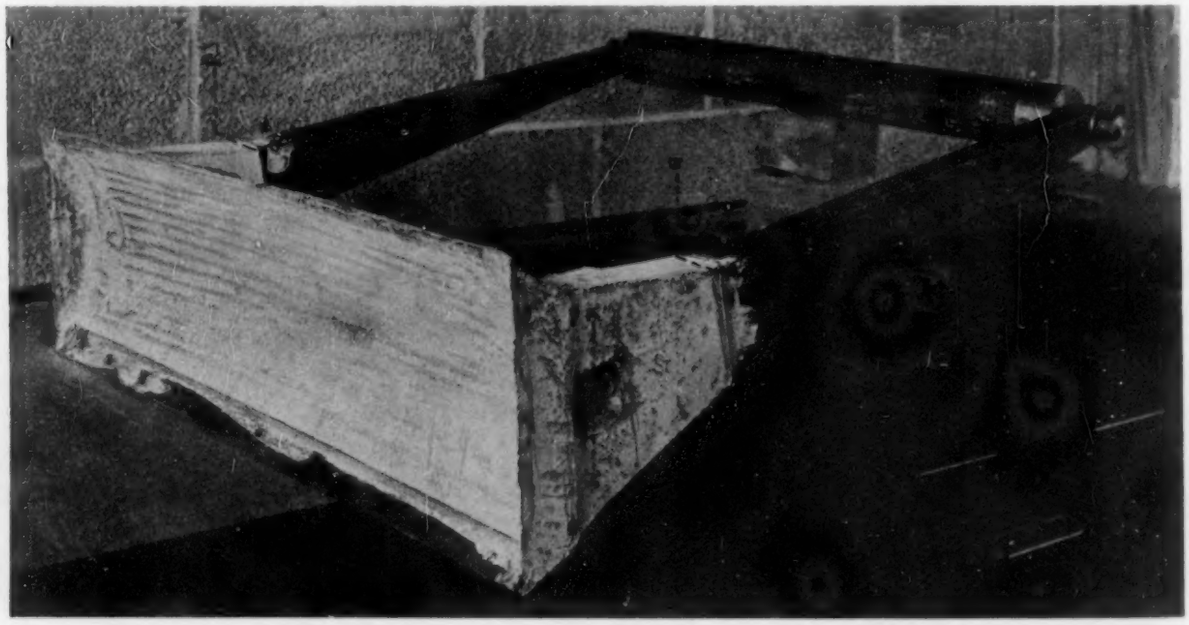


Fig. 6

inch were imposed without stressing the steel in the angle beyond the elastic limit.

When readings were taken at the surfaces of intersection between the sockets in the bowl with loading as described, the stress was concentrated and fairly intense near the upper inside corners of the socket.

Readings on the back center of the bowl were very small, hence necessitating the use of brittle coating of plaster of Paris wash to detect any movement and its orientation.

As a final test in this series, the bowl was filled with wooden form and then the bulldozer model was loaded centrally at the top, and the sockets carried the full wedging action of the tongues or side arms at points *F* and *G*, Fig. 6. The actual stress developed for a load equivalent to 50,000 pounds amounted to a maximum of 2920 pounds per square inch at the corner of the socket where the warpage due to welding in the tongue tended to wedge the socket open at point *G* in the above figure. The conclusion is therefore reached that a socket which is flanged at the small end opposite the bowl and welded around the edge of the flange, in the manner of welding the model, required no further change in design. Comparison of the old and revised design is shown in Fig. 8.

Description of Tests, Series 2

When strain gage readings were taken on the back center portion of the bowl the values were so small that it was practically impossible to detect any movement. However, it was evident from analysis and in placing the model in the machine and moving it from place to place that it showed weakness against twisting action. Since, in general service, when the corner of the bulldozer blade is used to cut into side banks, stumps. stones, etc., the opposite upper corner of the bowl is free to twist; the predominant stress results from the twisting action of the movement of the opposite corners of the blade. It was the purpose of these tests in Series 2 to find the points of inherent weakness of structure under this loading. In consequence, the model was set up as shown in Fig. 2, with the opposite corners blocked and acting against a central load imposed by the testing machine at the top ends of the side arms or tongues. To deduct the direction of metal flow with this loading, the model was painted with a plaster of Paris wash, which was later dried before testing. Loads then were applied

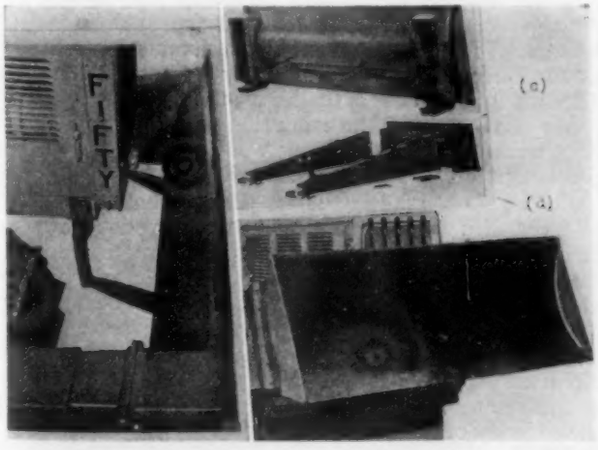


Fig. 7—Structural Details of 10-Ft. Bulldozer

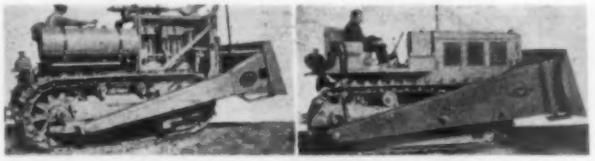


Fig. 8—Comparison of Types of Construction
A. Conventional Design B. Design According to Model Findings

until surface cracks developed in the plaster of Paris. During actual tests the cracks developed for loads beginning at 46,000 pounds. The most severe localization of stress was evident at the top of the socket, which had freedom in movement. Since the predominant action of the load is to produce severe twisting strains, a torsional member must be interposed between the sockets. This may be seen by comparing contour of the torsional member interposed between the sockets concentric with curvature of the bulldozer bowl at the outboard end. (Fig. 7*c*.) Space limitation on the tractor and bending requirements in manufacture prevent use of concentric torsion bowl fitted to rear of the main bowl.

As a final test, the concentric bowl was added by welding the ends of the sides of the respective sockets shown in Fig. 7*c* and welding edge seams to the back of the bowl. Equivalent load of 80,000 pounds was imposed on the steel bowl and structure as shown in Fig. 2 without cracks of any kind appearing in the plaster of Paris coating, and without relative deflection of the side arms. Assuming that the tractor before the engine stalls will deliver a force of 11,700 pounds against the bulldozer blade, it is evident that the actual test loads are 6.8 times the capacity of the tractor, and in no way prove detrimental judging from the model tests on the bulldozer. At the same time the appearance of the bulldozer unit has not been sacrificed and excellent stiffness has been obtained with the minimum amount of material. The actual weight of the bulldozer based on this design is computed as 300 pounds less than the present model, and will require approximately 7 more lineal feet of weld in fabrication.

In a complex structure of this type the model revealed the weaknesses and the effect of corrections. Aside from a few difficulties in welding sequence, the large size bulldozer has been satisfactory for shovel duties in rock and stump removal—duties much more severe than simple dirt removal.

Summary

1. Weld behavior depends upon conditions associated with deposition. Only by suitable tests such as hardness, stress-strain, photomicrographic studies and X-rays can prediction of weld performance be determined. Supplementary tests of welders and materials are equally as important. By these methods the guess in welding is partially eliminated.

2. Service loadings supply the most accurate measure of weld performance usually after failure has occurred. The probability of premature failure due to weld deposition or faulty design may be indicated in suitable model tests which simulate service conditions.

3. Welded models of intricate structures under load reveal the inherent defects. Stress concentrations in complex construction which a stress analysis does not evaluate, can readily be solved by use of welded models.

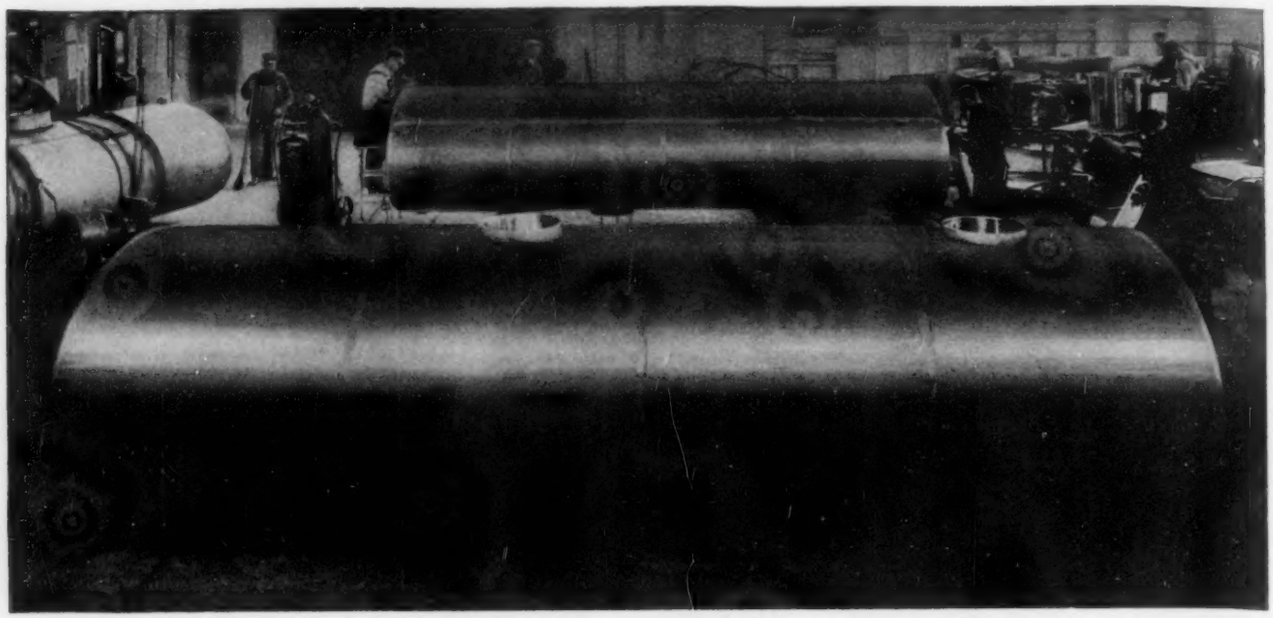


Fig. 1—Modern Production Practices

Improved Fabrication of 18-8 Chromium Steels

By DONALD R. PRATT†

Development of Columbium-Treated 18-8 Welding Rod a Great Step Forward

INTRODUCTION of the columbium-treated 18-8 stainless steel welding rod marks an important advance in the fabrication of stainless steel products.

The use of this rod in conjunction with 18-8 base metal "treated" or "stabilized" with columbium or titanium permits the fabrication of welded stainless steel products which, in the as-welded condition, have full resistance to corrosive and oxidizing influences, particularly at elevated temperatures.

18-8 Welding Characteristics

While no attempt will be made to go into a detailed technical explanation of the subject, a brief discussion of 18-8 stainless steel and its welding characteristics will assist in pointing out the reasons for the advantages of welds made with the new columbium-treated 18-8 welding rod.

Outstanding Properties.—The outstanding property of 18-8 stainless steel is its ability to resist many types of chemical corrosion, combined with a relatively high degree of ductility and malleability. Many industries, such as oil, chemical, food and dairy, pulp and paper, and many others have benefited greatly by the development of this alloy. The designer and builder of equipment for these fields thus has been given a steel from which equipment can be made that will have many times the life of other steels formerly used. In some cases it has found use where previously ferrous materials were not permissible.

Until recently a limiting factor in the use of 18-8 stainless steels was that certain service conditions had a tendency to lower their corrosion resistance by producing a susceptibility to intergranular corrosion. Welding also was found to cause the same susceptibility in narrow zones in the base metal near the weld. In some cases, heat-treatment after welding would restore the desired properties but this was not always feasible.

Carbon Content Important.—The carbon content of 18-8 stainless steel has an important effect on its corrosion resistance. Increase in the carbon content causes a rapid decrease in the ability of this steel to resist corrosion at elevated temperatures or after it has been heated during fabrication, as in welding. The so-called low carbon 18-8 stainless steel, which is the type most generally used for high corrosion resistance, is usually specified as maximum 0.10 or 0.07 per cent carbon depending on the severity of the intended service.

The metallurgical reasons for the development of susceptibility to intergranular corrosion can be explained as follows: When an 18-8 steel is cooled *rapidly* from high temperatures, as is normally done in its manufacture, the material retains a homogeneous structure,

† Technical Publicity Department, The Linde Air Products Co.

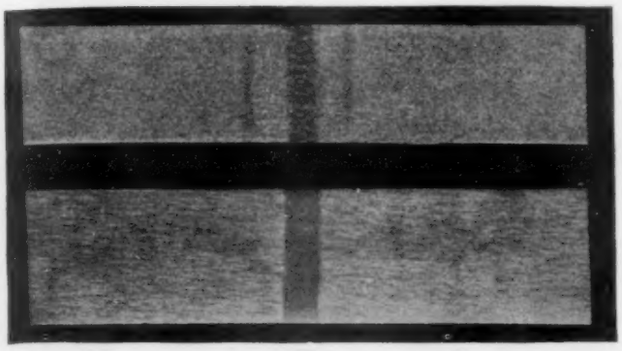


Fig. 2—These Two Specimens Illustrate the Effect of Adding Columbium to Stainless Steel. Top—Stainless 18-8 Steel, 0.06 Per Cent Carbon, No Columbium, Oxyacetylene Welded, Followed by Test in Nitric Hydrofluoric Acid Solution. Note Bands of Intergranular Corrosion on Each Side of Weld. Bottom—Stainless 18-8 Steel, 0.06 Per Cent Carbon, Containing 0.67 Per Cent Columbium, Oxyacetylene Welded, Similarly Tested in Nitric Hydrofluoric Acid. No Signs of Corrosion Are Apparent. The Difference in Appearance between the Weld and Base Metal in Each Case Is Due to the Inherent Difference in Structure between Weld Metal and Rolled Base Metal

with carbon and other constituents in solution with the iron base metal. In this condition it is quite corrosion-resistant. However, when this steel is reheated to a temperature within the approximate range of 500 to 1400° F., a new constituent, a carbide, is precipitated or thrown out of solution. This tends to form at the boundaries of the individual grains forming the metal structure. The formation of this precipitate lowers the corrosion resistance of the material at this point to a degree. This allows the destruction of the material by intergranular corrosion under conditions that it should normally resist.

In welding, then, the critical 500 to 1400° F. range is passed and exceeded. As the heat passes this range slight precipitation may take place, but the higher heat of welding permits complete solution to take place again. Cooling of the weld metal usually is rapid enough to prevent precipitation as the metal passes through the critical range. Thus the weld itself retains to a large extent the corrosion-resisting properties of the original base metal. There is a zone parallel to the weld in the base metal, however, that is brought to the critical range because of the welding heat. The metal in this zone remains heated within the critical range for a sufficient length of time and cools at a slow enough rate so that precipitation takes place and this zone is subject to intergranular corrosion. Before the advent of the newer "treated" 18-8 steels or the new welding rod, full corrosion resistance after welding could be obtained only by reheating the product to the high temperature necessary to put all of the carbon into solution again and cooling it rapidly.

Beneficial Effects of Columbium and Titanium.—A great deal of study was given this problem, with the result that certain elements were found which, when added to ordinary 18-8 stainless steel, would eliminate the susceptibility to intergranular corrosion. The elements of greatest value for this purpose are columbium and titanium. When either of these elements is added in such amounts as to create the proper balance between the added element and carbon, formation of the precipitate is minimized or eliminated. This preserves the corrosion resistance of the alloy steel, even when it is heated subsequently to within the critical range. This further eliminates the necessity of subsequent reheating or annealing to a temperature above that range, followed by rapid cooling after fabrication. This discovery led to the development of the so-called "treated" or "stabilized" 18-8 stainless steels which have a wide use in commercial applications when high corrosion resistance is necessary.

Columbium in the Welding Rod

While the presence of either element in the base metal is effective in eliminating the "heat effect," columbium is more advantageous for use in the welding rod. This element is not burned out of a rod of proper analysis to any extent during welding. The result is that an analysis of the weld and the metal adjacent to it shows that nearly all of the columbium of the rod has been carried through the welding process to give a "treated" weld fully as capable of resisting corrosion as before fabrication. Therefore, the use of "treated" or "stabilized" 18-8 stainless steel base material and the new columbium-treated stainless steel welding rod allow fabrication of a welded article that will have all of the desirable corrosion resistant properties of the base material without the need for subsequent heat-treatment.

Columbium is important in another way in that it counteracts the harmful effect of a slight carbon pick-up which is possible during the welding. The welding rod contains a sufficient amount of columbium to maintain the proper ratio to carbon and other alloying elements even after a small increase in carbon, to a maximum of about 0.10 per cent, resulting from welding.

Columbium Improves Welding "Untreated" Steel Also.—While the columbium treated welding rod was developed primarily to meet the problems of successfully welding the new "treated" or "stabilized" steel without subsequent heat-treatment, distinct advantages are found in using it for welding the ordinary untreated 18-8 steel. When it is used for welding straight 18-8 steel, its chief advantage lies in the fact that the columbium in the rod counteracts the effect of any possible pick-up of carbon during the welding process. This results in the production of weld metal having better corrosion resisting properties under service conditions than welds made with untreated rod.

Columbium Eliminates Cross Weld Effects.—There is another very important advantage. When straight "untreated" 18-8 stainless steel is used in crossed welds, that portion of the first weld which adjoins the second weld is affected in exactly the same manner as untreated base material. In other words, there is created a narrow zone of lowered corrosion resistant steel crossing the first weld and parallel to the second. In joining welds, as for example, in closing a circumferential weld, a similar condition results in the cold portion of the weld laid down at the beginning of the operation. These effects are entirely eliminated by the use of a welding rod containing columbium. This, as explained previously, is because the columbium remains in the weld metal to give a treated weld unaffected by reheating.

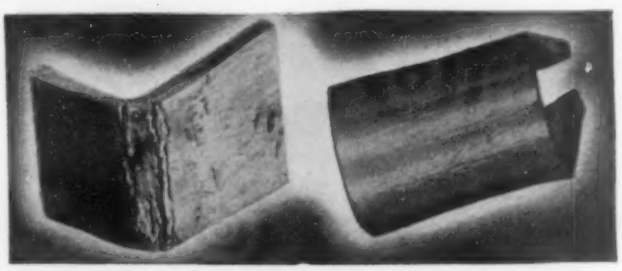


Fig. 3—A Bend Test (Right) in Columbium Treated 18-8 Stainless Steel, Oxyacetylene Welded, after Boiling for 400 Hr. in Acidified Copper Sulphate Solution. Note the Complete Absence of Cracking, Showing Absence of Intergranular Corrosion. Compare This with the Left Picture Showing an Untreated 18-8 Steel Specimen Similar in Every Way Except That It Did Not Contain Columbium

Welding Procedure

The procedure used in gas welding 18-8 stainless steel is essentially the same as in welding ordinary steel. The only difference lies in the fact that certain precautions must be more carefully followed. Greater care must be exercised in welding 18-8 steel, particularly of the "treated" or "stabilized" types, in order to obtain the most desirable results.

Flame Adjustment Important.—The properties of welds in stainless steels are greatly affected by the type of flame employed. The flame should be adjusted to give a neutral condition in which equal volumes of oxygen and acetylene are consumed. This regulation is understood and made without difficulty by those experienced in the use of the blowpipe.

Must Use Flux.—The use of Cromaloy flux is strongly recommended in welding 18-8 steel. It makes the control of the molten metal easier, and also insures a sound, clean, good-appearing weld.

The application of flux to either the seam or the welding rod can be easily and quickly done by mixing the flux with water to the consistency of a thin paste and applying with a brush. The use of flux on the rod is particularly helpful in welding light gage sheet. Advantages are also gained by painting the underside of the seam with flux, since this prevents oxidation and allows a more perfect union to be made along the bottom of the seam.

Welding Technique.—Welding should be conducted in such a way as to prevent or minimize any tendency to puddle the weld. Puddling of the weld should be avoided since it increases the tendency toward oxidation and removal of the valuable constituents. The preferable welding technique consists in holding the rod ahead of the blowpipe so that the molten metal melts in place or

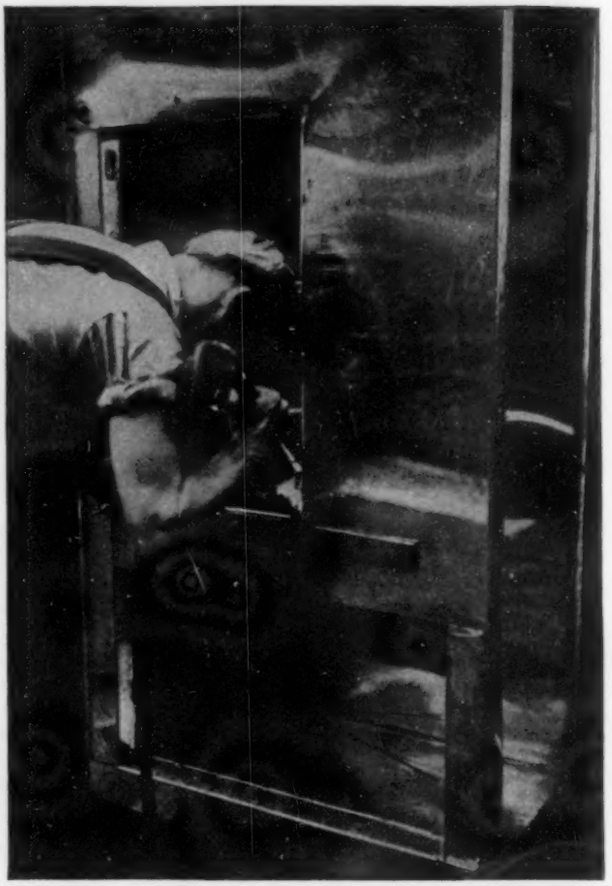


Fig. 5—The Use of Columbium-Treated Rod Perfects Welding of This Stainless Steel Refrigerator Box

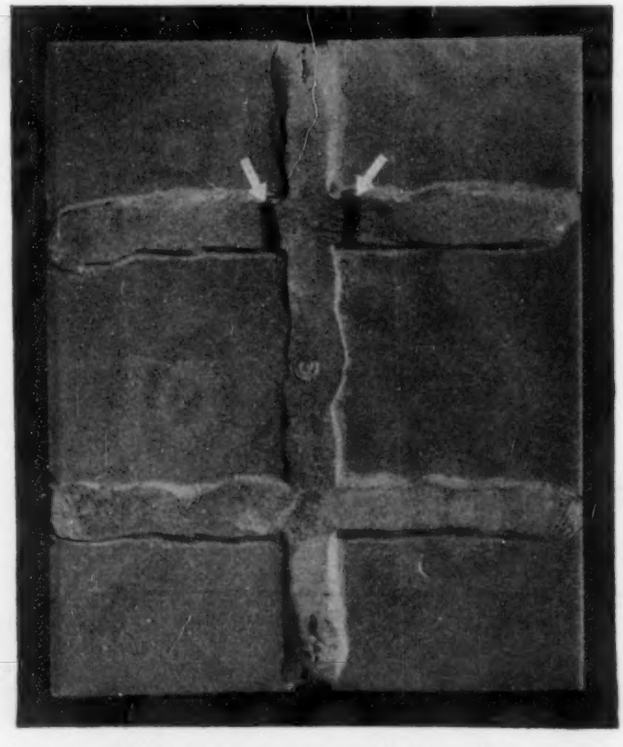


Fig. 4—Crossed Welds on "Treated" or "Stabilized" 18-8 Stainless Steel Plate Show the Elimination of Intergranular Corrosion by the Use of Columbium-Treated 18-8 Stainless Steel Rod. The Upper Cross Was Welded with Untreated Rod (Arrows Point to Effected Zones) and the Lower Cross (Marked C) Was Made with Columbium-Treated Rod. The Specimen Was Then Placed in Nitric Hydrofluoric Acid Solution

is melted simultaneously with the base metal to form a union between the parts being welded.

The heat used in welding stainless steel should be the minimum that will give the results desired. Excessive heat on molten columbium-treated 18-8 steel increases the loss of columbium during the welding. The normal heat keeps the loss of this element to a small allowable percentage of that contained in the rod.

The choice between forehand and backhand welding depends chiefly on the skill of the operator in either method. In general, forehand welding is preferable on light gage sheet, while backhand welding is better on the heavier gages.

When working on stainless steel, it is customary and advisable to weld from one side entirely. Care should be taken to fill the seam completely so that there will be no occasion to return to some point which should have been finished as the weld progressed.

It is important not to stop or to retrace a hot weld. If this must be done wait until the weld cools entirely.

If it should become necessary to go back over a weld, or if there is need for welding at the back side of the seam, in order to eliminate severe stresses the entire seam should be preheated before the flame is applied to the local area of the joint. Such preheating is frequently undesirable because of the likelihood of warping of the metal, and because slow cooling is harmful to the stainless steel. In other words, complete the weld in one pass, get thorough penetration in one pass, and do not make it necessary to work over or touch up a weld in any way.

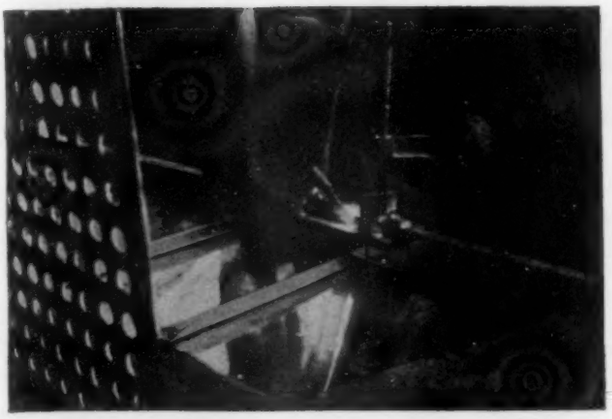


Fig. 6—Suitable Jigs Are Advisable for Work on Light Gage 18-8 Material to Eliminate Warping Tendencies

Another operation against which the operator must be cautioned is welding away from an edge. In case it is necessary to weld away from an edge, begin the weld an inch or two in from the edge, then return to the starting point later to complete the weld to the edge.

The operator should familiarize himself throughly with the recommended procedure before any fabrication is attempted. The columbium-treated rod flows easily and smoothly and very high quality welds may be expected. The welds will have good strength and will be completely corrosion resistant in the as-welded condition. The completed structure therefore may be used without the need of subsequent heat-treatment.

Simplifying Fabrication Problems

It has been found helpful to place the parts being joined so that the line of weld inclines slightly downward in the direction of the welding. In this way, the flux, which fuses at lower temperatures than the steel, can flow forward and consequently provide protection for the metal as it fuses.

As compared to ordinary steel, the 18-8 stainless steels have a much higher coefficient of expansion with, at the same time, lower thermal conductivity. Because of these properties, welding, especially when applied to thin material, may cause distortion and warping unless suitable provision is made to prevent this action. Clamps, copper chill plates, and jigs are used separately or in combination to hold the plates in line until the weld has cooled. Greater ease and speed in welding are other advantages obtained by the use of these appliances. Less absorption of heat in the part welded and more rapid chilling are also further advantages.

In most instances, sheets $^1/_{16}$ in. or less in thickness are flanged at the edge to a height of about $^1/_{16}$ in. The flanged edges are painted with the flux at both the top and bottom and are held in place as the flame melts down the flanges to form a smooth, moderately reinforced weld.

Slightly heavier sheets up to $^1/_8$ in. in thickness may have the edges butted together and welded with some addition of metal from a welding rod. A backing strip, generally of copper, is used beneath the joint to prevent the liquid metal from flowing out of the weld.

For plates heavier than $^1/_8$ in., the edges should be scarfed to provide a vee so that fusion entirely to the bottom of the weld can be obtained easily. Welding rod is, of course, used in making the weld.

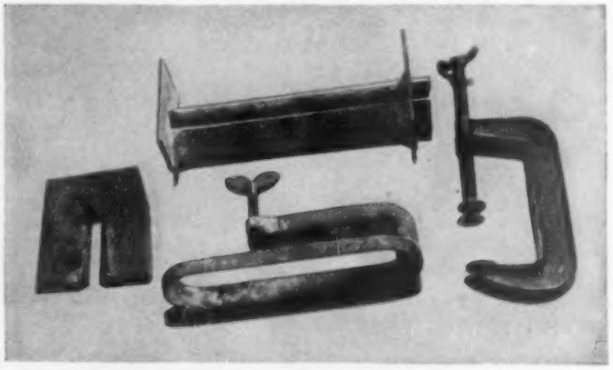


Fig. 7—Typical Clamps and Chill Plates Used in Stainless Steel Production Welding

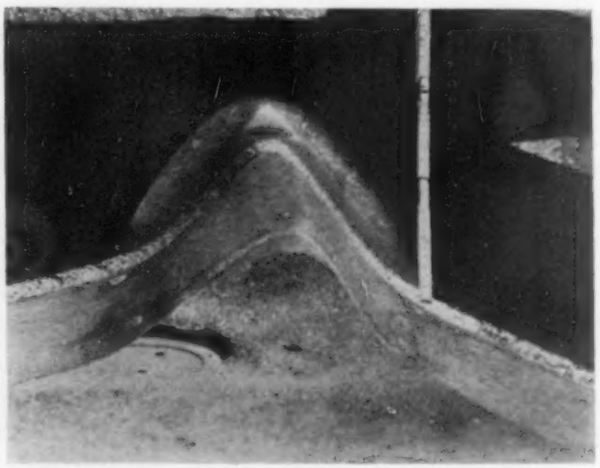
Test Proves Impact Value of Welds Made by the Electric Arc

By A. F. DAVIS†

Marietta Manufacturing Company, Point Pleasant, West Virginia, recently made an unusual test to determine the impact values of welds in construction of oil barges.

This company built up a 12-inch box section by welding two standard 12-inch channels together with $^1/_2$-inch plate 12 inches wide. This box section was placed on railroad ties spaced 8 feet apart. Then an 1800-pound weight was dropped on the test-piece approximately 100 times, starting from a height of 3 feet and continuing until a maximum of 6 times from 50, 60 and finally 75 feet was reached.

Condition of the test-piece after completion of the test is shown in the accompanying illustration. The weld was a $^1/_2$-inch fillet weld made in two passes with shielded arc.



Box Section Composed of Two Standard 12-Inch Channels Welded Together with $^1/_2$-Inch Plate Tested to Determine the Impact Value of Welds at Marietta Manufacturing Company, Point Pleasant, W. Va.

† Vice-President, The Lincoln Electric Co.

Spot Welding Problems*

By J. H. ZIMMERMAN†

IN keeping with the many advances and developments in other branches of welding, much substantial progress in the field of spot welding has been reported during the past eighteen months. While there have been no radical changes or improvements in the essentially simple basic practice, much development work has been done in connection with applications of the process in new fields. A brief review of recently published developments may well serve as an introduction to certain specific problems, progress in which is to be reported upon here.

Machines

Many new machine types[1,**] from small portable air-operated guns to large multiple hydromatic installations have been reported. One of the most interesting of these is the multiple hydroelectric welder[2] employing from 50 to 200 welding guns mounted at any angle connected to a common bus bar (secondary welding circuit) and to a common oil pressure line. The welds are fired one at a time with the proper timing automatically controlled. In one automobile body assembly 9 sheet metal parts are welded with 160 spots in 45 sec. Special machines and procedures employed in the manufacture of electrical meters have been described by Stickney.[3] Power requirement calculations for projection welders have been presented by Fassler[4,5] who stresses the need of increased power factors for welding machines. Briggs,[6] however, calls attention to the fact that efficiency may be robbed to pay power factor and suggests the product of the power factor and the efficiency to be a fair criterion for the comparison of spot welder performances. The A. I. E. E. have published standard[7] methods of rating, testing and designating resistance welding machines which should prove to be helpful.

Electrodes

The general subject of electrode materials has been given considerable attention and advances have been made toward developing materials which show long service life. The answer to this problem is a material which combines high electrical and high heat conductivity with high hardness. Advances in this direction in the development of the Cu-W and Cu-Cd alloys has been described by Perkins[8] and a general description of the application and performance of these alloys has been given by Ruppin.[9] Kelly[10] claims good results for a Be-Cu alloy although the experience of others has been that the addition of sufficient Be to produce maximum hardness (about 2.25%) lowers the conductivity excessively. An interesting new electrode employing a steel sheath as reinforcement against "mushrooming" has been described by Komovski.[11]

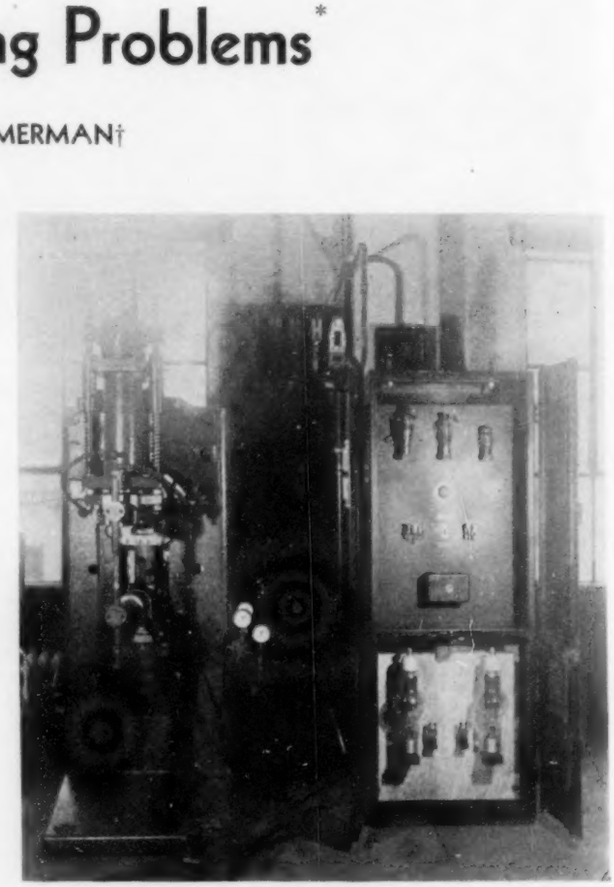


Fig. 1—Spot Welder and Thyratron Control Panel Used for M. I. T. Research Projects

Timing Devices

Probably the outstanding improvement in the spot welding process has been the perfection of the various time controllers now in wide use. The need for such time control has accompanied the application of the process to new materials, notably 18-8 type stainless steel and the light alloys. The development of a number of these control devices has been very well described by Briggs.[12] For extremely short timing the tube controls effectively eliminate inertia effects, excessive maintenance costs, arcing troubles and adjustment difficulties common to most mechanical contactors or controllers. The Thyratron tube control has been well described by Hutchins and Livingston[13] and the Ignitron tube together with an auxiliary synchronous photo-timer is well described by Stoddard.[14] Further discussion of the "ignitron principle" has been published by Silverman and Cox.[15] A very interesting light-beam bell-ringing indicator useful for the constant checking of spot weld currents has been fully described by Bohn.[16] The mechanical timer employed in the so-called "shot" welding process, a closely controlled spot welding procedure, is discussed in detail by Spraragen.[17] This time is novel in that it records the energy for every weld, gives an audible signal for faulty welds and can be transported to the work.

The important features and an interesting application of the spot welding process in the construction of a light traction car have been presented by Butler.[18] MacFar-

* Presented at Fall Meeting, AMERICAN WELDING SOCIETY, Chicago, Oct. 1, 1935. Contribution to Fundamental Research Committee.

† Asst. Prof. of Mechanical Engineering, in Charge of Welding and Metals Working Laboratories, Massachusetts Institute of Technology, Cambridge.

** Numbers refer to bibliography appended.

land[19] stresses the need for accurate time control and describes a simple mechanical cut-out switch to be used in conjunction with an air-operated spot welder.

Mechanical Properties

Data pertaining to the size and spacing of spot welds in general have been worked out mathematically and presented graphically by Briggs.[20] Means for conservatively estimating spot weld strengths and ideal ratios of spot and electrode diameters to sheet thicknesses are included. Improvement in the mechanical properties of spot welds by stress relieving is reported by Dussourd[21] in connection with a general discussion of the strength of spot welds in sheet steel up to 5 mm. thick. In a lecture before the French Welding Society[22] he states that spot welds are of maximum strength only when actual melting has occurred and that spot welding is in effect a typical fusion welding process. He recommends a reheating or drawing treatment by reheating between the electrodes after welding. Erofeeff[23] on the other hand reports troublesome gas bubbles and cracks in steel plate spot welds when too much heat is applied. Many investigators, however, report spot welding to be a recrystallization phenomena below the melting point as in forge or hammer welding. Whereas spot welding can be truly classed as a plastic welding process in many cases, it is equally true that melting does occur frequently and that classification as a fusion welding process is not wrong. Quinn[24] reports troubles from pipes or blow-holes in the cast or recrystallized structure in a spot weld in $^1/_4$ in. Ni steel plate. Some defective welds in this material were found to have high strength but no correlation could be obtained between variations in the procedure and resultant weld strength. All welded spots showed a coarse martensitic structure and were found to be quite brittle. Jones[40] has been unable to get consistent relations with welding procedure and mechanical properties of the spot weld in thin stainless steel and Goodman and Dalton[25] have had the same experience with Alclad sheet. The facts that spot welds are usually only lightly stressed in service and that the service loads are seldom known have contributed to the lack of fundamental information on the strength of spot welds in the commonly used materials. A number of special light built up beams, columns and connections as developed by the Budd Mfg. Company who have pioneered in spot welded light weight stainless steel construction have been published.[26]

Materials

Much research during the past eighteen months has been devoted to the development of the proper spot welding technique in applying the process to what may be termed, special materials. By special materials are meant all other than iron or low C steel, particularly those which are difficult for various metallurgical reasons. Specialized machines and procedures for unusual combinations of materials have been reported by Ferguson[27] whose work includes the spot-welding characteristics of some 250 combinations of metals studied in the Bell Telephone Laboratories. Outstanding work in this field has been done by Gillette[28] in the past few years. Each of the above investigators has worked out the necessary combinations of electrode materials, shape, etc., to produce satisfactory welds in many unusual combinations of materials and thicknesses.

In welding thin stainless steel of the 18-8 type it has been found necessary to control weld timing very accurately in order to avoid the formation of a corona of corrosive material surrounding the spot through the precipitation of carbides from the otherwise corrosion resistant solid solution alloy. By the proper procedure it has been found quite possible to confine such precipitation to the interior of the sheet and to hence preserve the stainless property at the surface. Recent reports in this field have been published by Spraragen,[17] Product Engineering,[26] Jones[40] and the results of a comprehensive series of tests has been reported by Hibert and published by the Chief of the U. S. Army Air Corps.[29]

In the field of light alloys the outstanding contribution of recent months has been the work of Hobrock[30] of the Daniel Guggenheim Airship Institute who proposes that spot welding, much like hammer welding, is due to recrystallization of the metal at temperatures below the melting point. He further finds that this recrystallization is affected by deformation of the metal and by the recrystallization temperature and these factors together with the mechanical and electrical structure of the welding machine and its control apparatus are discussed in their probable relation to the strength and reliability of the spot weld. Additional valuable work in the field of light alloys has been reported by Bohn,[31,32,33] Flight[34] and Goodman and Dalton.[25]

Fig. 2—Two Alclad Sheets in Contact. 100 X

Fig. 3—Section of a Multi-Stage Spot Weld in Alclad. 100 X

Fig. 4—Typical Oscillogram for a 3-Cycle Alclad Spot Weld of the Type Shown in Fig. 3

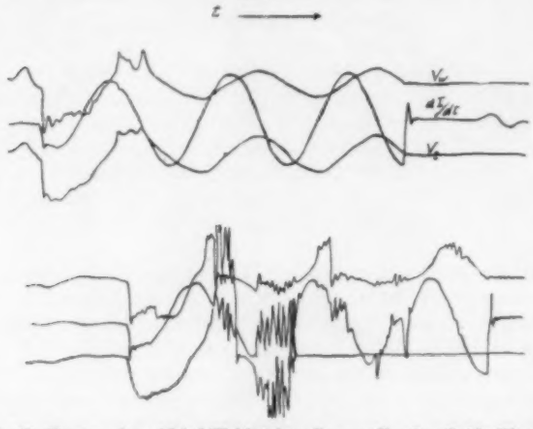


Fig. 5—Oscillogram of an Alclad Weld at Low Pressure Showing Oxide Film Break-Down Effects

Applications of Spot Welding

Industrial applications of the spot welding process may not properly belong in a survey of spot welding research, yet each new development is truly the result of much fundamental research and study and inclusion of a few of the more recent applications of the process may be in order. Numerous economic advantages are to be obtained by the substitution of spot welding for some other method of joining metals and much progress in new fields has been reported.

In the construction of aircraft the use of stainless steel and of high strength aluminum alloy sheet is becoming widespread. Progress in the development of spot welding technique for these two materials has been reported.[29,32,34,35]

The development of a light-weight car for city traction has been reported by Butler[18] and much valuable data employed in the design of a spot welded light-weight train has been published by Eksergian.[36]

In the automotive field the hydromatic welder[2] has proved itself to be successful and application to the process in many fields of light manufacturing have been reported by Stickney,[3] Perkins,[8] Westbrook,[37] Rodgers[38] and many others.

Problems under Investigation at the Massachusetts Institute of Technology

During the past year several student research projects in the field of spot welding have been undertaken in the M. I. T. Welding Laboratories. No one of the projects to be described here has been completed, in fact, one sometimes wonders if any true research problem *can* be completed. Yet, certain progress has been made and it is hoped that a brief outline of the investigations under way together with certain of the findings may be of interest to the members of this Society. The laboratory equipment used for the M. I. T. tests is shown in Fig. 1.

Alclad

The Alclad used in this investigation is a high strength aluminum alloy sheet (17ST) coated on each side with a thin layer of aluminum of high purity, the combination of these compositions resulting in a light sheet metal which has the high strength of the Duralumin core coupled with the corrosion resistance of the pure aluminum surfaces. The microstructure of two Alclad surfaces in contact is shown in Fig. 2.

The spot welding of this material is not simple for several reasons among which are the conductivity differences in the two compositions, the narrow plastic (or melting?) range in which the welding must occur and the irregularities of surface or contact resistance due to thin surface oxide films. This material can be and is spot welded successfully but the process is not used as extensively as the aircraft manufacturer, for example, would like to use it because of erratic or irregular results.

Goodman and Dalton[25,*] working in cooperation with Perry,[30,**] have studied the metallurgical aspects of Alclad spot welding and the accompanying electrical effects, respectively. They believe the multi-stage weld shown in Fig. 3 and quite frequently encountered in multi-cycle timing at low pressures to be due to the rapid heating and subsequent rapid cooling each time the current passes through zero as shown in the 3 cycle oscillograph record in Fig. 4. The surging effects shown in Fig. 4 are probably the result of oxide film breakdown during the first cycle.

Many very interesting oscillograms such as Fig. 5, for example, have been recorded which cannot be included here. The unusual effects in this case have been attributed to the combination of low electrode pressure and high current although this is largely a matter of speculation.

Welding pressures have been found to be limited on the low side by high contact resistance, overheating and piping as shown in Fig. 6. They are correspondingly limited on the high side by excessive surface "brinelling."

The general effect of increased welding current settings has been found to be three-dimensional growth of the welds as shown in Figs. 7, 8 and 9. Troubles from too much heat are clearly evident in Fig. 9. One corner of the spot in Fig. 8 at higher magnification is shown in Fig. 10. A similar magnification of another spot shown in Fig. 11 seems to indicate a complete coating of pure aluminum around the spot. Such a structure would be ideal if it could be duplicated consistently.

It is apparent that times of greater than two cycles are unnecessary if not undesirable for best results using material of the thickness studied (0.035 in.). The ideal timing will naturally vary for other thicknesses but there has been no study in this direction as yet.

Fig. 6—Pipe and Shrinkage Cracks in an Overheated Alclad Weld. 100 X

* Undergraduate students in Aeronautical Engineering.
** Graduate student in Electrical Engineering.

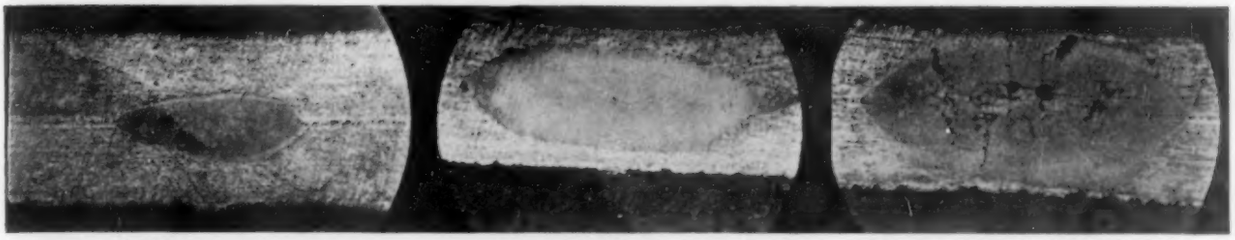


Fig. 7—Alclad Weld—Low Heat—25 X Fig. 8—Alclad Weld—Medium Heat—25 X Fig. 9—Alclad Weld—High Heat—25 X

Electrode Deterioration

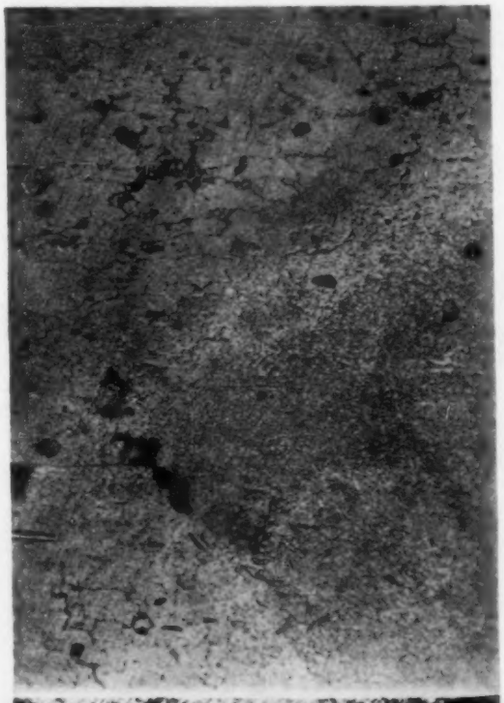
One of the outstanding problems encountered in spot welding certain materials is the frequent need for electrode redressing. This is particularly true in the case of hard drawn 18-8 type stainless steel for two reasons: first, the relatively greater hardness of the sheet steel as compared to the electrode, and second, the need for exact welding control in order to avoid defective welds. By electrode deterioration in this connection is meant any change in the electrode contour or surface which may result in faulty welding.

The variables or factors influential in determing electrode contour life are so numerous as to render precise isolation and study extremely difficult by their multiplicity.

The more important factors influential in this respect may be summarized as (1) electrode design and material, (2) heating effects, and (3) welding pressure. Unfortunately, each of these items is in turn made up of a number of variables. The design of the electrode might include any one of an almost unlimited number of contours, for example.

In an attempt to isolate and study certain of the obviously more important factors as far as electrode deterioration is concerned Jones[40,*] has conducted tests which will be briefly outlined.

Fig. 10—Alclad Weld—Boundary Zone of Fig. 8—100 X



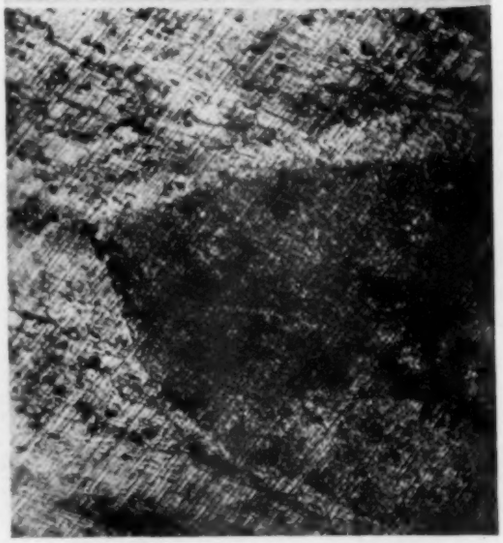


Fig. 11—Alclad Weld—Showing "Alclad" Spot—100 X

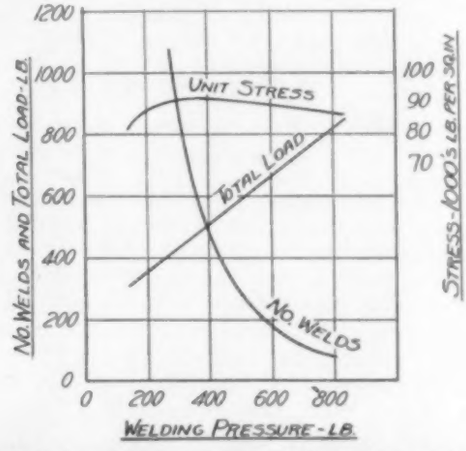


Fig. 12—Plot Showing the Effects of Increased Electrode Pressure on the Total Pull, Shear Stress and Electrode Contour Life When Welding 0.028-in. Thick 18-8 Type Stainless Steel

The procedure has consisted essentially in the establishment of a set of welding conditions which would give a satisfactory weld and with a repetition of welding with all conditions closely controlled until gradual changes in the electrode tip resulted in unsatisfactory spots.

The first step in such an investigation has necessarily been the establishment of a set of specifications which would act as a dividing line between acceptable and unsatisfactory welds. The following requirements were selected as reasonable for single spots in the 0.028 in. 18-8 sheet employed for these tests:

Min. tensile pull	400 lb.
Max. fusion	80 %
Min. fusion	50 %
Min. twist before failure	90°

* Undergraduate Student in Business and Engineering Administration.

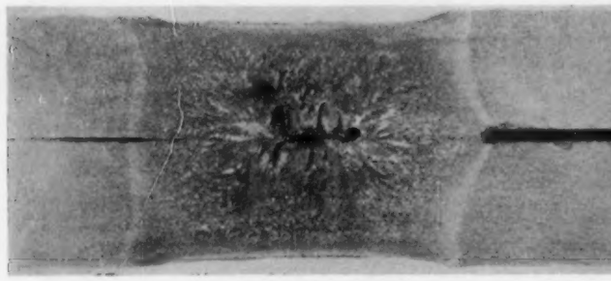


Fig. 13—Spot Weld in 1/4-In. Structural Nickel Steel Plate. Pressure 5000 Lb. 200 Kva. 62 Cycles

Fig. 14—Spot Weld in 1/4-In. Structural Nickel Steel Plate. Pressure 3000 Lb. 200 Kva. 91 Cycles

The variables which have been partially investigated to date include electrode design, electrode material and welding pressure. The present findings have not been checked sufficiently to warrant any statements concerning the relative merits of the special electrode alloys under test. Preliminary tests indicate the advisability of water cooling, as is well known, but they also indicate that if too much of the tip is hollowed out, water cooling can be overdone. This effect is due to loss of metal cross section with subsequently higher current densities and lower heat conducting capacity.

A general idea of the type of test result obtained in this investigation is shown in Fig. 12. In this illustration the number of spots to be obtained before defective welds occur is seen to be some inverse function of the pressure. However, higher pressures are seen to give higher weld pulls although the unit shear stress values are not greatly effected.

The complex interrelationships of the many variables involved in this problem indicate an extremely large amount of additional experimental work before any real facts concerning electrode failures can be published.

Nickel Steel

An extremely interesting and complete investigation of the possibility of satisfactorily spot welding structural nickel steel plate has been conducted by 1st Lt. H. A. Quinn.[24,*] This work was directly supervised by Mr. W. L. Warner of the Watertown Arsenal where all testing was done. A comprehensive study of the effects of heat and pressure variations on the physical and metallurgical characteristics of the spots was made.

In general it was concluded that the spot welding of 1/4 in. structural nickel steel plot was undesirable because of excessive porosity, shrinkage cracking, hardening and irregularity of properties. Some typical results are shown in Figs. 13 and 14. It is possible that with a machine of different characteristics better results might have been obtained.

Structural Applications

A number of research projects involving the determination of design data for light spot welded sections and reinforced sheets have been conducted. This work has been done under the direction of Prof. J. S. Newell. Many test specimens such as those illustrated in Fig. 15 have been tested. To date the experimental work in this field has been restricted primarily to what might be termed over-welded constructions in which the welds have not entered into the failures. As light structures of this type fail by lateral buckling effects, continuation of these studies with particular attention to the size and spacing of the spot welds may show some interesting results.

* Graduate Student in Special Ordnance Course at M. I. T.

[1] Miller, "Substantial Developments in All Types of Welding," *Iron Age*, Jan. 3, 1935, p. 154.
[2] "Dodge Uses Hydromatic Welders in Making All Steel Bodies," *Iron Age*, June 21, 1934, p. 22.
[3] Stickney, "Types of Resistance Welds and How They are Used," *Product Engineering*, May 1934, p. 162.
[4] Fassler, "Projection Welding and Power Consumption," AMERICAN WELDING SOCIETY JOURNAL, Nov. 1934, p. 14.
[5] Fassler, "Effect of Design and of Operation on Power Factor of Resistance Welders," *Welding Engineer*, Dec. 1934, p. 18.

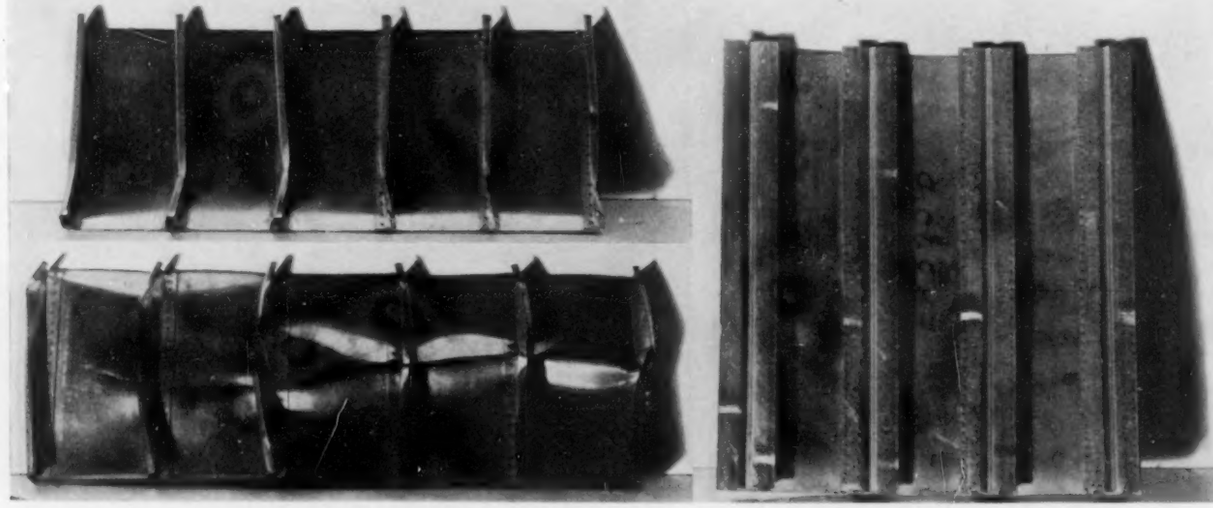


Fig. 15—Buckling Failures in Spot Welded Stainless Steel Test Specimens

[6] Briggs, "Robbing Efficiency to Pay Power Factor," AMERICAN WELDING SOCIETY JOURNAL, Mar. 1935, p. 19.
[7] "Standards for Resistance Welding Apparatus," *A. I. E. E. Stds.*, No. 39, Jan. 1934, p. 10.
[8] Perkins, "Making Dependable, Speedy, Economical Resistance Welds," *Welding Engineer*, Sept. 1934, p. 30.
[9] Ruppen, "Wear Resistant Elkonite and Elkaloy Electrodes for Resistance Welding and Heating," *Electrowärme*, Vol. 4, June 1934, p. 138.
[10] Kelly, "New Resistance Welding Electrode Alloy," AMERICAN WELDING SOCIETY JOURNAL, July 1934, p. 11.
[11] Komovski, "A New Design of Spot Welding Electrode," AMERICAN WELDING SOCIETY JOURNAL, July 1935, p. 14.
[12] Briggs, "The Development of Resistance Welding Electrical Power Control Devices," AMERICAN WELDING SOCIETY JOURNAL, Mar. 1934, p. 8.
[13] Hutchins and Livingston, "Thyratron Tube Control of High Speed Resistance Welders," AMERICAN WELDING SOCIETY JOURNAL, Nov. 1934, p. 19.
[14] Stoddard, "New Timer for Resistance Welding," *Electrical Engineering*, Oct. 1934, Vol. 53, No. 10, p. 1366.
[15] Silverman and Cox, "High Power Welding Rectifier," *Electrical Engineering*, Oct. 1934, Vol. 53, No. 10, p. 1380.
[16] Bohn, "Light Beam Indicator for Aluminum Resistance Welding," *Metals and Alloys*, Mar. 1935, p. 70.
[17] Spraragen, "Shot Weld Closely Controlled Welding Process," *Iron Age*, Sept. 27, 1934, p. 18.
[18] Butler, "A Light Weight Car for City Traction Service," AMERICAN WELDING SOCIETY JOURNAL, Nov. 1934, p. 2.
[19] MacFarland, "Improving Quality of Spot Welds," *Welding Engineer*, Nov. 1934, p. 15.
[20] Briggs, "Size and Spacing of Spot Welds," AMERICAN WELDING SOCIETY JOURNAL, Nov. 1934, p. 25.
[21] "Proprietes Mechaniques des Soudures par Points," *Usine*, Vol. 43, Oct. 11, 1934, p. 37. Abstracted in *Metals and Alloys*, Jan. 1935.
[22] Dussourd, "Contribution to the Study of the Mechanical Properties of Electric Spot Welds," *Bul. de la Soc. des Ingenieurs Soudeurs*, Vol. 5, 1934, p. 1391. Abstracted in *Metals and Alloys*, Jan. 1935.
[23] Erofeeff, "Investigation on the Row Electric Spot Welds," *Autogennoie Delo*, No. 9, 1934, p. 15. Abstracted in *Metals and Alloys*, April 1935, p. 150.
[24] Quinn, "The Spot Welding of 1/8 In. Nickel Steel," M.S. Thesis, M. I. T., 1934.
[25] Goodman and Dalton, "An Investigation of the Problem of Spot Welding High Strength Aluminum Alloy Sheet," Thesis, M. I. T., 1935.
[26] "Light Weight Design with Spot Welded Stainless Steel," *Product Engineering*, Vol. 5, July 1934, p. 242; Aug. 1934, p. 293.
[27] Ferguson, "Spot Welding," *Bell Laboratory Record*, Dec. 1934, p. 10.
[28] R. T. Gillette, Private Communications, Works Laboratory, General Electric Co., Schenectady, N. Y.
[29] "Spot Welding and Its Application to Aircraft Structure," Air Corps Technical Report No. 3901, Air Corps Information Circular, Vol. VII, No. 692, July 10, 1934.
[30] Hobrock, "Some Fundamentals of Spot Welding Especially of the Light Alloys," *Metals and Alloys*, Jan. 1935, p. 19; Feb. 1935, p. 41; Mar. 1935, p. 67.
[31] Bohn, "Resistance Welding of Aluminum and Its Alloys," AMERICAN WELDING SOCIETY JOURNAL, Apr. 1934, p. 4.
[32] Bohn, "Spot Welding Aluminum Alloys," *Aviation*, Aug. 1934, p. 256.
[33] Bohn, "Spot and Seam Welding of Aluminum and Aluminum Alloys," *Sheet Metal Industries*, July 1934, p. 426.
[34] "Spot Welding Light Alloys," *Flight*, Dec. 20, 1934, p. 1365.
[35] Flader, "Stainless Steel in Aircraft Construction," *A. S. M. E. Trans.*, May 1934, Vol. 56, No. 5, p. 295.
[36] Eksergian, "Design of Light Weight Trains," *A. S. M. E. Trans.*, Sept. 1934, Vol. 56, No. 9, p. 667.
[37] Westbrook, "Fastenings Where Spot Welds Are Cheapest," *Electrical Manufacturing*, Feb. 1934, Vol. 13, No. 2, p. 22.
[38] Rodgers, "Resistance Welding," *Electrical Review*, Jan. 4, 1935, Vol. 116, p. 12.
[39] Perry, "An Investigation of the Electrical Characteristics of Short-Time Spot Welding," M.S. Thesis, M. I. T., 1935.
[40] Jones, "A Study of Electrode Deterioration in Spot Welding Thin Stainless Steel," Thesis, M. I. T., 1935.

Proposed Uniform Test Procedure for the Qualification of Operators of Welding Equipment*

IN the development of fusion welding applications, progress has been made only by offering to the user definite assurance of the integrity of the welds. The most positive determination for this is, of course, the non-destructive exploration or test of the welded joint, but where that form of test does not appear to be warranted, the plan of qualifying the welding operator by tests of welds made by him is, by common consent, regarded as the most effective safeguard for weld quality. In fact, most of the welding codes and specifications recently formulated, contain more or less complete requirements for such qualification tests, some of which are applicable even when non-destructive tests of the welds are called for.

Due to the varying conditions under which these qualification practices have arisen, however, there has been a lack of uniformity of plan or purpose among them, and the variations, involving tests of both processes and operators, have been a cause of considerable confusion and trouble to the welding industry. Neither the manufacturers or contractors nor the welding operators have been satisfied with the present practices. As a result, insistent demands for relief from this situation have come to the Society and as a result a Committee has been appointed to correlate the requirements of existing codes relating to tests of welding operators. This Committee is actively at work and is preparing to soon offer recommendations that will, it is hoped, tend to eliminate further confusion by correlating the varying qualification test requirements and merging them into one uniform code which will be adequate to satisfactorily qualify welding operators to work under any and all codes, using any of the established fusion welding processes.

It is now well established that a welding operator will *normally* be inclined to perform welding of a quality as good as his training and ability permit for any particular process and type of filler metal. One of the important elements to ensure quality welding is therefore that the operator be qualified to perform the desired type and quality of welding. Qualification tests should therefore be directed toward determining the ability of the welding operator to produce results that should normally be expected from the particular process and procedure with the grade of filler metal used. The results thus obtained constitute the most practical available measure of the proficiency of the welding operator.

One of the difficulties most commonly encountered in establishing suitable qualification tests for welding operators is the fact that all such tests of operators are to a greater or lesser extent tests of the welding process as well. The operator, in order to demonstrate his ability to obtain complete penetration and proper fusion and the best ductility possible, must use suitable welding equipment, filler material and procedure with which to properly perform the test welds or his efforts will be automatically nullified. It is therefore difficult to entirely divorce the qualification test of the operator from the process influence, and it can be stated that it is the purpose of this Code to recognize both of these features and prescribe tests which will not only prove the capability of the welding process, but also single out the operator's mental and manual characteristics in applying it. This division of the essential elements will require two different series of tests, one to be comprehensive and quantitative to

* Approved by the Executive Committee of the AMERICAN WELDING SOCIETY.

prove the welding process and procedure itself, and the other a simplified qualitative test merely to check the welding operator's ability to apply that particular process and procedure

As an initial step in the testing and qualification of an operator of welding equipment it is essential that the welding procedure itself be checked in order to prove that it is capable of producing welds which will meet the required tests. It is conceivable that a welding operator that is known to be experienced and able might fail to qualify if not furnished proper welding equipment and materials for the tests. It has, therefore, seemed advisable to divide the Code into two parts as follows:

Part I—Qualification of the Welding Process and Procedure for Any Group of Materials and Conditions.

Part II—Testing of the Welding Operator to Determine His Ability to Properly Apply the Above Qualified Process and Procedure.

The Committee is now engaged in the important and difficult task of providing under Part I for adequate methods of qualifying the various fusion welding processes and procedures, but at this stage of its work the rules will be limited to the welding of ferrous materials, principally the non-alloy steels that have a carbon content not exceeding 0.35%. Effort has been made to provide tests that will be sufficiently critical to determine the ability of any welding process and procedure to adequately meet the requirements of any code or welding specification that may be involved. It is the intent of these rules to provide that the tests covered by Part I shall constitute merely an initial qualification of the process and will not require repetition if the conditions involved are not changed.

With the qualification of the process established as provided for in Part I it will be the intent of these rules that welding operators who are to operate thereunder need only submit to a very brief and inexpensive set of check tests, the purpose of which is to determine their ability to satisfactorily apply the established process. Great pains have been taken to remove from this phase of the qualification procedure, any tests that may be considered tests of the process rather than of the operator. The advantage of this plan in saving of both time and expense can be readily appreciated. The result will be more adequate treatment in Part I of the welding process in general, and at the same time, brief, inexpensive yet decisive check tests of the welding operators to determine his ability to apply the process in question.

The work of formulating the processed new test procedure is rapidly approaching completion. The Committee expects, in the near future, to submit the proposed procedure as a tentative set of rules for publication in the JOURNAL, whereupon general criticisms thereof will be invited.

C. W. OBERT
Chairman, Committee on Correlation of Code Requirements for Qualification of Welding Operators

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Self-Sharpening and Other Effects on Wear Resisting Metals*

By CHESTER MOTT†

IN ORDER for a tool to dig it must have a certain shape, but usually the digging operation begins immediately to destroy that shape and to impair the effectiveness of the device. This is true whether the material to be dug is highly abrasive or just mildly so; whether it be soft dirt or broken rock.

A little study of the self-sharpening effect brings out some fundamental ideas concerning hard-facing and makes possible a better understanding concerning the kinds of hard-facing to be applied and how, and often indicates whether hard-facing should or should not be employed.

One simple device for producing the effects of abrasion consists of a vertical spindle to which is attached an arm or arms which rotate in a horizontal plane. A satisfactory machine for this work is a drill press. Place on the table of the drill press a pan of greater diameter than the arms and fill this pan to a depth of 4 or 5 inches with crushed tungsten carbide. Now attach to the arms various specimens to be tested and raise the table until the desired depth of immersion of the specimen in the tungsten carbide is attained. We can now rotate the arms and thus simulate the effect of certain digging tools. Pressures can be varied by varying depths of immersion. Speeds may be altered, wet or dry conditions of abrasion obtained, meshes of material changed and naturally a great variety of shapes of tools may be tried, angles of attack altered, etc.

My purpose is not to take you through a maze of such trials, but to illustrate the self-sharpening principle. Suppose we consider two materials for a moment. Glass and talc or soapstone. I ought to be safe here from any accusation of trying to peddle some trade-marked material. Let's take specimen No. 1 and attach it to the arm, inclining it say 20° ahead of vertical. This is simply a piece of $^1/_4$-in. square soapstone ground off square on the end. At the same time, we prepare another piece exactly as No. 1 except that we cement onto the front edge a piece of 0.005-in. thick glass, making the glass flush with sides and bottom. Call this specimen No. 2.

* Presented at meeting of Los Angeles Section, A. W.
† Stoody Company.

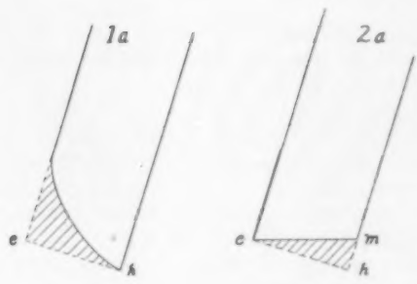


Fig. 1 Fig. 2

Now if we start our machine, in 30 minutes we'll have something like the conditions in 1*a* and 2*a*. They are quite different in appearance. Let's call the leading edge "*e*" in each case and the heel "*h*." We see that in 1*a*, "*e*" has disappeared, while in 2*a*, "*e*" is still intact. But "*h*" in 1*a* has not been removed, while "*h*" in 2*a* has vanished. Specimen 1*a* is said to be dulled and 2*a* is said to be sharpened. 1*a* is decidedly undesirable and 2*a* is desirable. Wear has not been defeated in either case, but we have manipulated wear in our favor in case 2*a*. And I think here is a point worth making. While we may in many cases reduce wear, we still haven't found a material to eliminate it. Just the same, if we can control wear and confine it to those places where its existence is not greatly disadvantageous, that achievement may be a great boon.

What would be the result of continuing the rotation of these specimens? Figure 3 shows 1*a* and 2*a* after continued operation and there is to be noted in the self-sharpened case that the glass is protruding beyond the end of the specimen. What happens from now on is a matter of the properties of the facing and its backing.

The facing should be brittle enough so that after sticking by for a certain distance, it breaks off and restores the situation of 2*a*. It should break off flush, i.e., the character of the material and its bond should be such that the whole piece doesn't lift off. It should not be so ductile that it will bend back. As to the support, it should be rigid enough so that it supports the hard-facing.

Now if we consider 1*a* again, I think it can be said that this curve, whatever it may be, is the curve that results from the abrasion of any homogeneous material, be it lead or tungsten carbide. No homogeneous material is inherently self-sharpening. Self-sharpening results from a difference in abrasive resistance. This contrast in properties is what brings about the desired result. It can be seen that regardless of what the original shape of No. 1 might have been, eventually it will assume some such curve as 1*a*.

If that be true, then we must have regard for the thickness of the facing. Obviously the sharpness is a function of the thinness of the facing. The thinner the facing, the sharper our tool, because the facing itself dulls according to the curve of 1*a*.

To pursue the matter of "how much" a little further, one can hardly fail to note that the conspicuous failures of hard-facing often arise through the use of too much metal. The zealots who have reasoned that if a little hard-facing is a good thing, a lot must be a great improvement, have done the industry a great deal of harm. Let's go back again to 2*a* for a moment. It can be seen that to face the bottom of the specimen along "*em*" is to defeat the self-sharpening prospect for it remains sharp by virtue of the tendency of the line "*em*" to retreat upward.

We can illustrate one more phenomenon of abrasion with our device. Suppose instead of using soapstone for our specimen 2*a*, we substitute balsa wood and attach a glass facing. We then find, instead of rapid wear back on the heel, a stubborn resistance to wear. This specimen I show you was given 15 times as many r.p.m. as 2*a*. You will see that the heel has worn back very little. This is a case of the specimen building up its own armor. The nature of the balsa wood is such that small particles of the tungsten carbide are embedded in the wood and so form an excellent wear resisting surface. Thus is explained the case of soft facing materials exhibiting fine records of resistance to abrasion. The metal acts as a cement or bond to attach particles of the abrasive material to itself and use them as a shield. From experiments like this, we soon learn that in few instances is hardness the criterion in judging a facing material.

The attack on metal may involve any or all of the 4 following means: Corrosion, impact, sliding, rolling.

For the ordinary methods of abrasion resistance, corrosion is not a serious factor and it is usual to consider the latter 3. Probably the most important class of service hard-surfacing metals are required to withstand is that of the abrasive action of non-metallic material such as soil, sand, gravel, crushed rock, ore, vegetation.

Industry has been reluctant to embrace hard-surfacing metals, though some progress has been made lately and

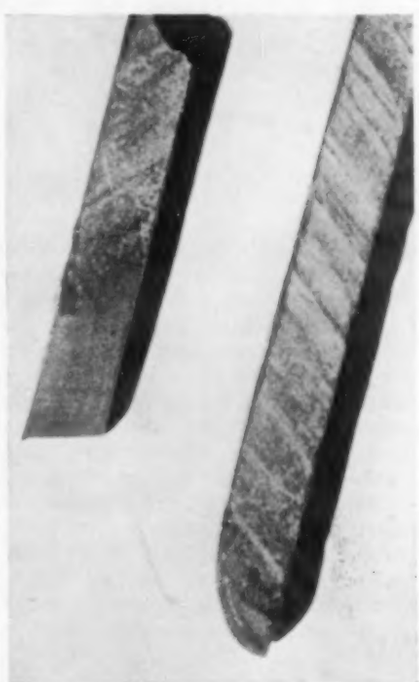


Fig. 3

there is great promise. Inserted valve seats is a victory for the hard metal people.

At present writing though, the great grist of hard metal is applied by the user himself in the reclamation of worn out parts or the treatment of new parts to arrest abrasion. In order for the user to apply these metals intelligently, he should study their characteristics with the idea that there is no one best material for all purposes; that he cannot lift pages from another's experience and insert them in his book. The successful user of hard metals makes a careful study of worn parts, undertakes to reconstruct the abrasive action and then knowing the properties of the various hard metals available, sets out to establish a defense against wear.

He should have a table of at least 6 properties something like this:

Cohesiveness	Resistance to Impact
1	1
1	2
3	5
4	3
5	4
6	6

Hardness	Smoothness of Deposit
6	5
5	2
4	1
3	4
1	3
2	–

Thinness of Welding	Ability to Scour
5	3
1	2
2	5
4	1
3	4
–	–

In the use of tables one considers the part to be treated and list the factors that must obtain in the hard-faced part. For example let's consider a plowshare to be used in sandy soil, having some rocks. It would mean then that we would have to provide against impact, and that scouring would not be important. But smoothness of deposit and thinness of welding are requisite to eliminate the necessity for grinding after welding. The hardness would have to be fairly good in order to insure the self-sharpening effect, for the edge of a plowshare cannot be blunt, so then we would list our properties.

Impact	Smoothness of Deposit	Thinness	Hardness
1	5	5	6
2	2	1	5
5	1	2	4

In deciding on our material it appears that material five comes nearest to answering our requirement, and it works out this way in practice.

Another case might be that of a cable tool bit. Naturally this tool would have to be withstanding considerable impact, and cohesiveness would be an important factor for we do not want chunks of bits left in the hole. Hardness would not be an important consideration, in fact we would probably keep on the soft side. The other factors are of secondary importance, so in this case we would list our properties as follows:

Impact	Cohesiveness	Hardness (reverse order)
1	1	2
2	2	1
5	3	2

Material one would seem to be the solution, and this is the fact.

The Welding of Copper-Nickel-Molybdenum Steel*

By HOWARD L. MILLER†

THIS paper deals with the practical production welding of copper-nickel-molybdenum steels as conducted in several body shops engaged in making up truck tanks and dump bodies for highway truck transportation of gasoline, fuel oils, ink and for solid commodities, such as coal, ice and building materials; rubbish and garbage truck bodies; and general purpose transportation units.

The object in using a high tensile steel in this class of work is to reduce tare weight and increase pay load. Reductions of 30 to 50% in the gages of plates and sheets bring increased fiber stress in these structures and practically force the adoption of welding in order to utilize the full strength of the metal. A steel for this class of work must be ductile enough to form cold in regular fabricating tools, such as presses and brakes and it must be capable of being welded as easily as regular carbon steel. It must not produce hard or brittle welds and the welds and adjacent parent metal must be ductile and shock resistant enough to be put into service without heat treatment after welding.

The elimination of all air hardening elements, such as chromium, silicon, vanadium and the addition of copper, nickel and molybdenum in suitable proportions result in an alloy with an inherently high strength in the ferrite which is not greatly dependent for its strength on its rate of cooling through the critical range. The copper, nickel and molybdenum in the proportions used dissolve completely in the ferrite and do not combine with the carbon. It is possible to produce sheet and plate from 18 gage up to $^1/_2$ in. plate and find them very close together in physical properties after a normalizing treatment.

The first application which we will consider is that of truck tanks for gasoline and fuel oil transportation.

* Presented at the Fall Meeting, AMERICAN WELDING SOCIETY, in Chicago, week of September 30th.

† Republic Steel Corporation.

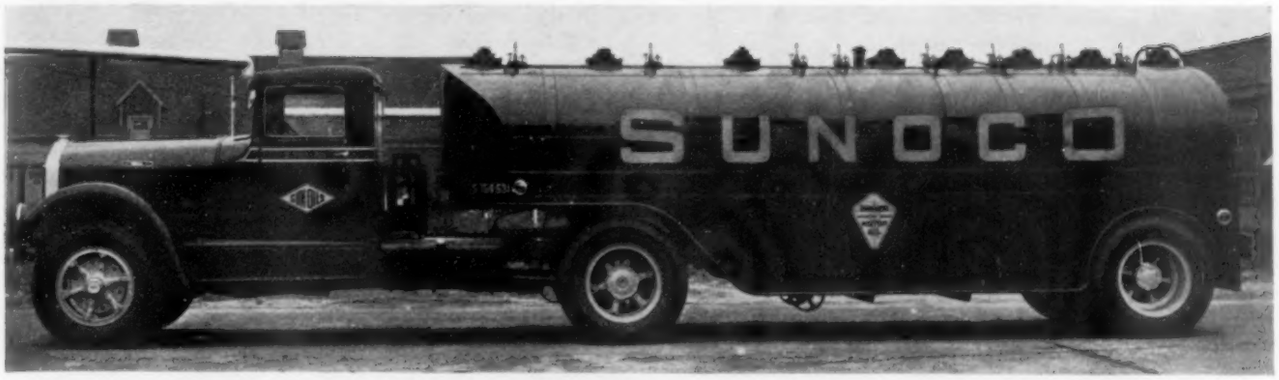


Fig. 1

There are over one hundred welded tanks of this steel now in service. The tank in Fig. 1 is a 3100-gallon unit with six compartments and is entirely welded in all tank seams and supporting members. Twelve-gage heads and 14-gage shells are sufficiently strong to carry its load and these sheets are three gages thinner or about 33% thinner than common steel sheets for the same loading.

A representative sample of the sheets used for this application shows the following analysis and physical properties:

C	Mn	P	S	Si	Cu	Ni	Mo
0.095	0.70	0.017	0.028	0.03	1.44	0.75	0.07

Yield Pt.	Tensile	El. 2 In.
69,800	82,400	33%

The tensile tests on butt welds all broke well away from the weld without showing any drop in strength from the original sheet. The lap welds due to the shear and bending moment, broke along the weld between the sheets but passed the yield point of the steel sheet before breaking at about a 5000 p.s.i. lower value than the butt weld tests.

Figure 2 shows the Rockwell B hardness readings through the zone of welding.

Drop tests on the welded tanks of this analysis were made by another fabricator.

Figure 5 shows a 14 ga. tank of 150 gallon capacity after it had been filled with water and dropped 18 feet to land on its side on a creosote block floor. This drop caused a considerable deformation of the metal but no cracks or leaks were found.

Figure 3 shows the same tank after a second drop from a height of 23 feet landing on a steel plate.

Hardness

Rockwell B hardness readings were taken along the welds and sheets of each type of weld. Figures 2a and 2b are drawings showing the location of the Rockwell impressions together with a tabulation of the hardness values.

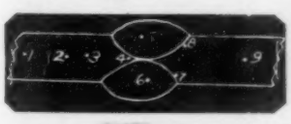


Fig. 2a—Butt Weld

Position	Rockwell B 12 ga.	14 ga.
1	83	80
2	88	81
3	87	81
4	92	92
5	85.5	87
6	91	90
7	89	83
8	89	83
9	85	78

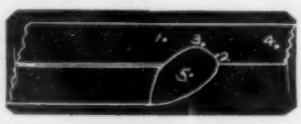


Fig. 2b—Lap Weld

Position	Rockwell B 12–14 ga.	14 ga.
1	90	83
2	94	92.5
3	93	83.5
4	86	83
5	89	92

Figure 4 shows the side which struck the plate turned up to your view. Note the extreme deformation in metal and in welds. This tank held all its water content in the second test without a failure of metal or weld.

Test welds, lap and butt, as made by another fabricator bent 180° flat over the weld without rupture.

Steel with these characteristics should be able to give a good account of itself in service. This grade is made to a specified 0.12 max. carbon.

Another grade with the same manganese, copper, nickel and molybdenum but with about 0.25 carbon has been very successfully applied to heavy duty dump bodies. This steel is furnished in normalized sheet and plate to a minimum 70,000 Y.P. and 90,000 tensile.

Figure 6 shows a large coal truck body of all welded fabrication. A reduction of 1635 lb. from an estimated weight for a regular steel body of 5000 lb. gives a body weight of 3365 lb. for this truck with a rated 11-ton capacity. The pay load increase is about 10% made from 12-gage sheets. This job is nearly two years in service making 10 to 15 trips a day and has given no trouble or required no repairs since its installation.

Figure 7 shows a smaller job with a more modern idea of lines. This job is also an all welded construction of 180 cu. ft. capacity and made of 12-gage sheets. 118 square feet of 16 gage used in skirting and portions. In service nearly one year to date.

Figure 8 shows an entirely different type of body. This body or rack for case goods is made of 16- and 18-gage strip steel all welded by arc methods. The reduction is 50% from former practice.

The welds on $^1/_4$-in. plate in both the low and intermediate carbon grades show the same characteristics as in the higher gages.

On the low carbon grade with a Rockwell of 87–91 B scale on the normalized plate the first bead showed only 4 points lower hardness after the second bead was applied than the plate, while the second bead in the "as welded" condition showed only three points higher than the plate. This gives us a spread of less than 10 points Rockwell in the welded zone, without treating the weld. These hardness conditions are more uniform than can be obtained with any air hardening type of steel.

All of the welded fabrication has been done with are welding and the use of heavy coated wire. Some of these wires use regular direction and some reversed polarity. With the proper heat no difficulty has been experienced in welding this material. Several of the rods made in general production by various companies have been successfully used. The opinion of the writer is that, given any good type of rod properly coated, the weld is dependent on the welder himself and that although the coating and analysis of rod and coating may

be attributed to science, the welding operating is an art, a work of hand, eye and brain. No welding machine operator can be successful without a comprehensive background of hand welding experience.

We believe that the welder's field in the transportation industry is wider than ever before, and that welded fabrication will ultimately replace the rivet not only on truck bodies but also on rail cars.

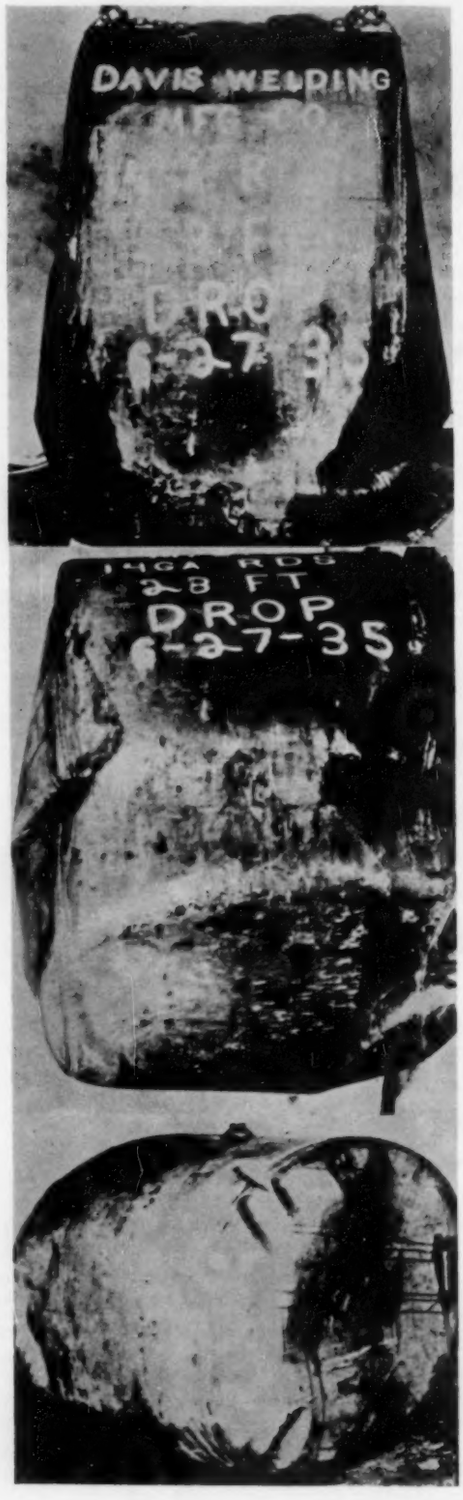


Fig. 3—Test Tank as It Landed on Steel Plate from a Height of 23 Feet. No Leaks Found after the Double Drop of 18 and 23 Feet

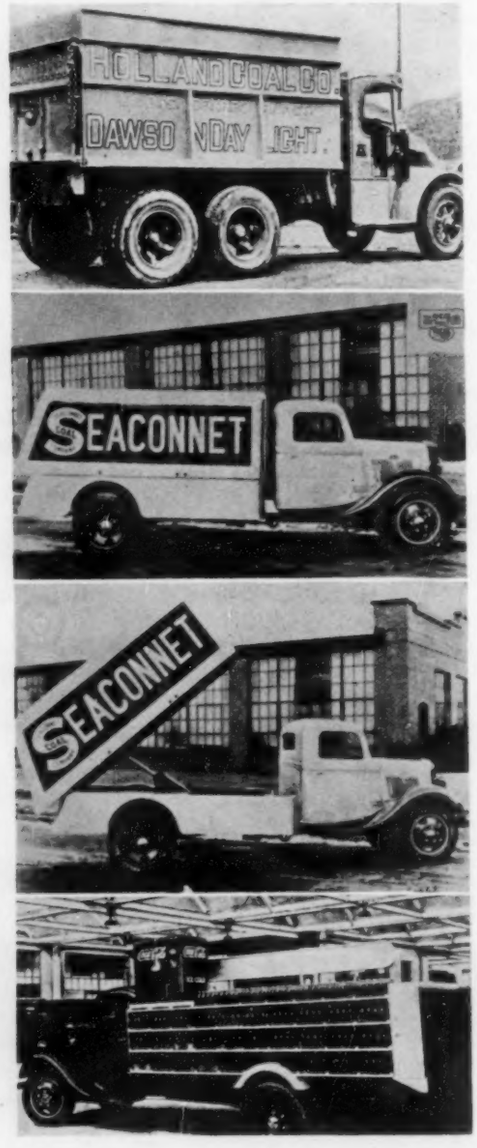
Fig. 4—Side View of Above

Fig. 5—Tank after First Drop of 18 Feet. No Leaks Were Found and It Required 5 Gallons of Water to Refill Showing Tank Had Stretched Considerably

Fig. 6—Large Welded Coal Truck

Fig. 7 (*a* and *b*)—Smaller Truck Made of 12- and 16-Gage Steel

Fig. 8—New High Tensile Steel Bodies. Reduction in Weight 50 %



6

7a

7b

8

Paper on Residual Stresses*

A Note of Some Additional Results, Available Too Late for Publication in the Paper, and Presented at the Chicago Meeting

By R. E. JAMIESON

Effect of Stress-Relieving

AN additional specimen of the series described in the paper, referred to as plate number 10, from the same stock and identical in every way with the long plates numbers 1, 3, 5 and 6, was stress-relieved at 1150° F. after welding, and then tested in tension in the manner described. Figure 7 shows the separate graphs of the strain on the two gage lines, and the dotted straight line indicates the mean curve for normal material as obtained from plate number 7. The differences of strain on the two gage lines at any given stress are very small throughout.

Figure 8 shows the graph of the mean strain for plate number 10. The dotted line representing the mean strain for normal material coincides with this graph up to a stress of about 25,000 pounds per square inch, above which the graph diverges, indicating progressive yielding. The yield point stress, as determined by the drop of the beam, was 30,000 pounds per square inch. It may therefore be inferred that localized residual tension stresses after the stress-relieving were of the order of 5000 pounds per square inch, being the difference between the normal yield stress and the stress at which progressive yielding can first be detected. This figure is in line with previous results, and lends confirmation to the idea that comparative information on conditions of residual stress may be obtained from simple tension tests as described.

The ultimate strength of plate number 10 was 52,000 p.s.i., and the drop-of-beam yield point was 30,000 p.s.i.; corresponding average figures for the normal material were 52,900 and 29,700, respectively. The elongation of this plate was approximately 33%, the same as that found for plate number 7. The stress-relieving procedure applied to plate number 10 was evidently entirely effective in restoring the material, for all practical purposes, to its condition prior to welding.

I would like also to call attention to two typographical errors in the paper as published in the September issue, namely,

Page 16, 2nd column, 2nd paragraph, 12th line "qualitatively" should read "quantitatively."

Page 17, Table I, line C, 3rd column, "−12650" should read "−16250."

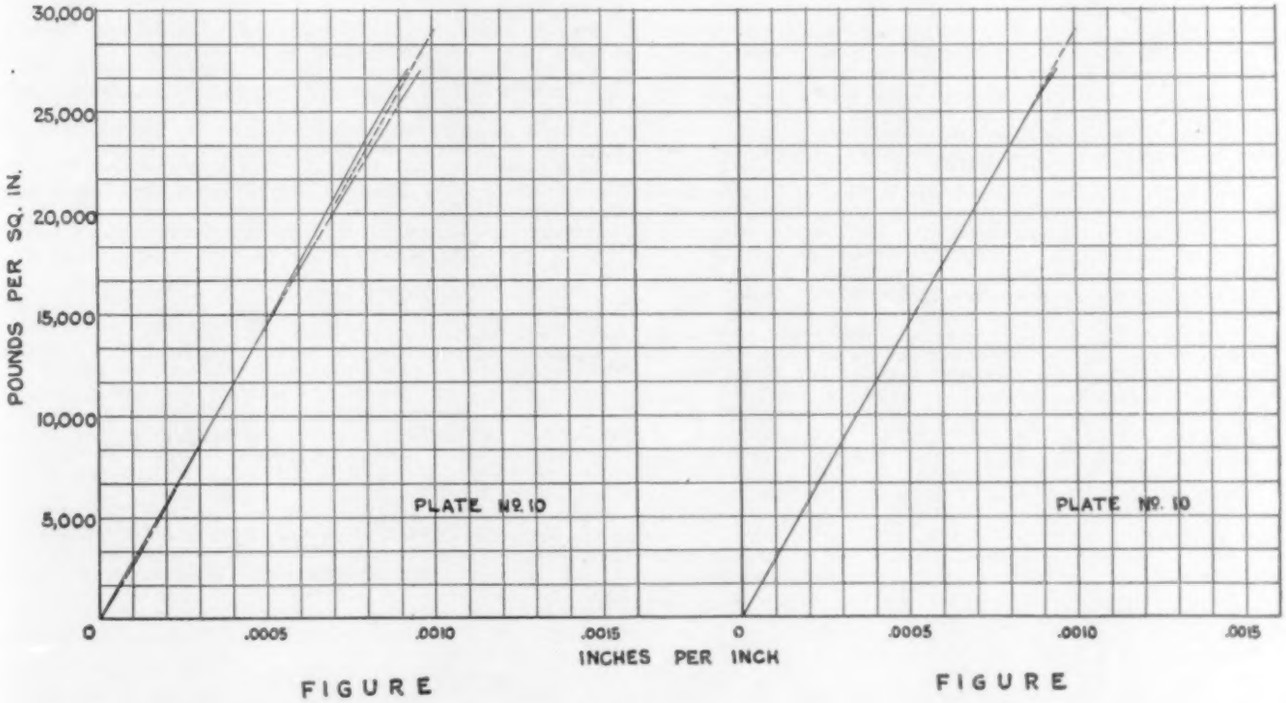


FIGURE 7

FIGURE 8

* A. W. S. JOURNAL, September 1935.

CURRENT WELDING LITERATURE

Airplane Manufacture. Aircraft Construction Welding, R. F. Taylor. Welding J. (July 1935), vol. 32, no. 382, pp. 206–208.

Airplane Manufacture. Reliability of Aircraft Welds, N. F. Ward. Am. Soc. Mech. Engrs.—Trans. (Oct. 1935), vol. 57, no. 7, pp. 389–394 (AER 57-2).

Aluminum. Welding Aluminum with Metallic Arc, A. Meyer, Jr. Welding Engr. (Sept. 1935), vol. 20, no. 9, pp. 29–31.

Automobile Manufacture. Resistance Welding Extensively Employed in Automotive Industry, J. A. Weiger. Iron Age (Nov. 7, 1935), vol. 136, no. 19, pp. 20–24 and 102.

Boilers, High Pressure. High-Pressure Boiler with Fusion-Welded Drums. Mech. Eng. (Aug. 1935), vol. 27, no. 8, p. 521.

Boilers, Tubular. New Braceless All-Welded Tubular Boiler Proves Strength in Test, G. W. Plinke. Power Plant Eng. (Oct. 1935), vol. 39, no. 10, pp. 578–580.

Bridges, Steel. Lessons Learned in Welding Steel-Plate Bridge Floor, H. H. Hawley and J. C. Merrell. Eng. News-Rec. (Oct. 3, 1935), vol. 115, no. 14, pp. 472–474.

Bridges, Steel. Bridge-Welding Procedure, H. H. Hawley and J. C. Merrell. Eng. News-Rec. (Nov. 7, 1935), vol. 115, no. 19, p. 649.

Bridges, Steel. Progress in Welding Large Railway Bridges, O. Bondy. Ry. Gaz. (Sept. 27, 1935), vol. 63, no. 13, pp. 492–496.

Bronze Welding. Welding Bronze to Steel, C. H. Jennings. Elec. J. (Aug. 1935), vol. 32, no. 8, pp. 317–318.

Buildings, Steel. Erection of Steel Buildings. Am. Soc. Civ. Engrs.—Manuals of Eng. Practice, no. 9, 1934, 19 pp.

Car Building. Welded Underframes in New Lehigh Valley Cars, J. E. Tesseyman. Welding Engr. (Sept. 1935), vol. 20, no. 9, pp. 66–67.

Cars, Sleeping. New First-Class Sleeping Cars, L. M. S. R. Engineer (Aug. 23, 1935), vol. 160, no. 4154, p. 202.

Construction Equipment. Welding on All-American Canal Project, J. C. Coyle. Welding Engr. (July 1935), vol. 20, no. 7, pp. 34–35. Large draglines negotiate desert sands and silt; cracks in bucket repaired by welding on plates; repaired eccentrics have been in use for several years; procedure for repairing cracked frame; etc.

Electric Machinery. Cost and Weight Reduced by Welding Fabrication. Elec. World (Sept. 28, 1935), vol. 105, no. 20, p. 27.

Electric Welding in Textile Industry, R. H. Friend. Textile Inst.—J. (Oct. 1935), vol. 26, no. 10, pp. P347–355.

Electric Welding, Arc. Effect of Welding Variables on Physical Properties of Electric Arc Weld Metals, R. R. Blackwood. Instn. Engrs. Australia—J. (Nov. 1934), vol. 6, no. 11, pp. 421–443. Effect of deposited electric arc weld metal of electrode gage, size of run, welding current and plate thickness on Brinell hardness, yield point, ultimate tensile strength, elongation, reduction of area and Izod impact value; statistical methods are used in analyzing results.

Electric Welding, Arc. Electric Arc Welding and Its Applications, M. Lebrun. Welding J. (June 1935), vol. 32, no. 381, pp. 168–171; (July), no. 382, pp. 198–201.

Electric Welding, Arc. Metallic Arc Welding, H. Harris. New York, Longmans, Green & Co.; London, Edward Arnold & Co., 1935. 199 pp., illus. diagrs., charts, tables, $6.00. Survey of arc welding; process and its equipment; methods of testing welds; influence of oxygen and nitrogen; aging of weld metal; welding of steels of various types and of copper and nickel and their alloys; principal applications of arc welding. Eng. Soc. Lib., N. Y.

Electric Welding, Resistance. Factors to Consider When Designing Parts for Projection or Spot Welds, A. M. Wallace. Machine Design (Aug. 1935), vol. 7, no. 8, pp. 26–29.

Electric Welding, Resistance. High Voltage Condenser Welding. Power Plant Eng. (Nov. 1935), vol. 39, no. 11, pp. 628–630.

Electric Welding, Resistance. Fundamental Data on Resistance Welding, A. M. MacFarland. Welding Engr. (Sept. 1935), vol. 20, no. 9, pp. 40–43.

Electric Welding, Resistance. Modern Resistance Welding, P. W. Fassler. Automobile Engr. (Sept. 1935), vol. 25, no. 336, pp. 327–328.

Electric Welding Machines. Electric Seam Welding Machines. Engineer (Aug. 23, 1935), vol. 160, no. 4154, pp. 190–192.

Ferryboats, Diesel. All Welded Diesel Ferry Berkley. Motorship (Sept. 1935), vol. 20, no. 9, pp. 336–337; see also Log (Sept. 1935), vol. 25, no. 6, pp. 10–11; and Mar. Rev. (Sept. 1935), vol. 65, no. 9, p. 22.

Gas Producers. New Design in Automatic Mechanical Gas Producers, A. E. Gibson. Steel (Nov. 4, 1935), vol. 97, no. 19, pp. 43–45.

Girders. Arc-Welded Bridge Girders Tested to Failure, L. Grover. Eng. News-Rec. (Sept. 19, 1935), vol. 115, no. 12, pp. 392–394.

Ice Plants. Oxyacetylene Cutting and Bronze Welding in Ice Plant Maintenance, W. D. Wilkinson, Jr. Ice & Refrig. (Aug. 1935), vol. 89, no. 2, pp. 94–96.

Iron and Steel Plants. Arc Welding in Steel Plant, W. H. Burr. Elec. J. (Sept. 1935), vol. 32, no. 9, pp. 355–357.

Machine Tool Manufacture. Designers' Problems with Welded Steel in Machine Tools, R. E. Kinkead. Machine Design (Sept. 1935), vol. 7, no. 9, pp. 46–49.

Metals Testing. Investigation of Behavior of Metals under Deformation at High Temperatures. I—Structural Changes in Mild Steel and Commercial Iron During Creep, C. H. M. Jenkins and G. A. Mellor. Iron & Steel Industry (Sept. 23, 1935), vol. 8, no. 13, pp. 515–521; (discussion) 554–555; see also Iron & Coal Trades Rev. (Sept. 20, 1935), vol. 131, no. 3525, pp. 434–435.

Motorboats. Novel Method of Constructing Steel Motorboats. Motorship (Oct. 1935), vol. 20, no. 10, pp. 370–371.

Motorboats. Steel Hull Motorboats. Motorship (Oct. 1935), vol. 20, no. 10, pp. 378–379.

Motorships. All-Welded Motor Ship "Joseph Medill." Iron & Steel of Canada (July–Aug. 1935), vol. 18, no. 4, pp. 58–60 and 61.

Oil Wells. Experiments Lead to Development of New and Interesting Technique in East Texas Welded Casing Practice, B. Mills. Oil Weekly (Aug. 5, 1935), vol. 78, no. 8, pp. 19 and 21.

Oxyacetylene Cutting. Torch Deseaming, W. S. Farr. Steel (Sept. 2, 1935), vol. 97, no. 10, pp. 38–40.

Oxyacetylene Welding. Locomotive Repair Operations Speeded by Oxyacetylene Welding and Cutting, D. C. Reid. Boiler Maker & Plate Fabricator (Sept. 1935), vol. 35, no. 9, pp. 247–248.

Oxyacetylene Welding. Safety Rules and Precautions in Use and Handling of Oxyacetylene Equipment and Gases. Welding Engr. (July 1935), vol. 20, no. 7, pp. 31–33.

Petroleum Pipe Lines. Welding Speeds Up Line Pipe Construction. Iron Age (Sept. 12, 1935), vol. 136, no. 11, pp. 24–27.

Pipe Lines. Welded Piping in Air-Conditioned Department Store, W. F. Barron. Welding Engr. (Sept. 1935), vol. 20, no. 9, pp. 37–39.

Railroad Crossings. East Grand Rapids Belt Grade Separation, L. W. Millard. Welding Engr. (Aug. 1935), vol. 29, no. 8, pp. 24–25.

Railroad Electrical Engineering. Association of Railway Electrical Engineers Committee Reports. Ry. Elec. Engr. (Oct. 1935), vol. 26, no. 10, pp. 231–258.

Railroad Repair Shops. Welding Practices in Modern Railroad Shop, R. R. Royal. Welding Engr. (Sept. 1935), vol. 29, no. 9, pp. 50–56.

Roof Trusses. Welded Construction, C. Helsby. Electric Welding (Aug. 1935), vol. 4, no. 24, pp. 205–215.

Shearing Machines. Simple Design for Pair of Welded Portable Pneumatic Shears, W. S. Whiting, Jr. Welding Engr. (Aug. 1935), vol. 20, no. 8, pp. 17–18.

Shipbuilding, Electric Welding. Electric Arc Welding in Shipbuilding. Mar. News (Sept. 1935), vol. 22, no. 4, pp. 43–47.

Shipbuilding, Electric Welding. Service Records of Welded Ships Excellent, F. G. Martin. Metal Progress (Sept. 1935), vol. 28, no. 3, pp. 51–53.

Shipbuilding Materials. Radiographic Inspection, M. M. Hutton. Mar. Eng. & Shipg. Age (Oct. 1935), vol. 40, no. 10, pp. 381–382.

Shrinkage. Experimental Determination of Shrinkage Stresses in Butt-Welded Joints, G. Bierett. Int. Ry. Congress Assn.—Bul. (Sept. 1935), vol. 17, no. 9, pp. 1185–1198.

Stainless Steel. Welding the Stainless Steels, A. P. Johnston. Welding Engr. (Aug. 1935), vol. 20, no. 8, pp. 19–22.

Steam Pipe Lines. Installing Piping in Cramped Quarters, G. W. Hauck. Heating, Piping & Air Conditioning (Apr. 1935), vol. 7, no. 4, pp. 194–195.

Steam Pipe Lines. Design of Modern Industrial Piping Systems—Flexibility of Piping, F. L. Snyder. Heating, Piping & Air Conditioning (Apr. 1935), vol. 7, no. 4, pp. 181–186.

Steam Pipe Lines. Welding High Pressure-High Temperature Steam Piping, S. Crocker. Heating, Piping & Air Conditioning (Feb, 1935), vol. 7, no. 2, pp. 81–84; (Mar.), no. 3, pp. 133–136.

Steel Castings in Welded Structures, C. Tolan, Jr. Product Eng. (Oct. 1935), vol. 6, no. 10, pp. 377–378.

Steel Castings. Welding as Aid to Making of Quality Steel Castings, C. M. Underwood and E. J. Ash. Welding Engr. (Sept. 1935), vol. 20, no. 9, pp. 60–65.

Steel Plates. Experimental Investigation of Cracking in Mild Steel Plates and Welded Seams, E. G. Coker and B. P. Haigh. Instn. Naval Architects—Trans., vol. 77, 1935, pp. 193–203; (discussion) 203–207, 3 supp. plates.

Structural Steel. Arc-Welded Structural Steel. Welding Engr. (Aug. 1935), vol. 20, no. 8, pp. 31–33.

Structural Steel. Positioning Steel Assemblies for Welding, R. E. Kinkead. Welding Engr. (July 1935), vol. 20, no. 7, pp. 29–30.

Welds, Testing. Consideration of Qualification Tests for "Class 2" Arc Welding, R. B. Lincoln. Welding Engr. (Sept. 1935), vol. 20, no. 9, pp. 68–70.

Welds, Testing. Developments in X-ray Method of Examining Welded Joints, J. C. Hodge. Boiler Maker & Plate Fabricator (Sept. 1935), vol. 35, no. 9, pp. 230–235.

Welds, Testing. Weld Metal and Rolled Steel; How Do They Work Together? R. Jensen. Welding Engr. (Aug. 1935), vol. 20, no. 8, pp. 26–29.

Welders, Training. Training of Electric Welders. Engineering (Sept. 6, 1935), vol. 140, no. 3634, p. 245.

Welding. Distortion-Control Procedure, D. Boyd and G. Cape. Welding Engr. (July 1935), vol. 20, no. 7, pp. 19–23.

Welding. Modern Methods of Welding, C. H. Davy. Instn. Chem. Engrs.—Advance Paper mtg. Oct. 9, 1935, 23 pp. Notes on forge-and-hammer, acetylene, electric-resistance-butt, atomic-hydrogen and metallic-arc fusion welding.

WELDING SOCIETY ACTIVITIES AND RELATED EVENTS

SOCIETY NEWS

Each month this column will contain a brief description of some important phase of Society News

Welding in the Design, Construction and Repair of Highway and Railroad Bridges

About a year ago a Committee was appointed by the AMERICAN WELDING SOCIETY to study welding of highway and railroad bridges with a view to preparing a set of specifications covering this work. The personnel of the Committee was selected with the utmost care in order to obtain the best talent available. Mr. P. G. Lang, Jr., Engineer of Bridges of the Baltimore & Ohio Railroad, was selected for the Chairmanship of the Committee. Although the use of welding in the construction of bridges dates back to 1922, it was realized that some pioneer work including a study and digest of recent literature and test reports had to be done before suitable specifications could be prepared. Because of its volume, the work was divided among various subcommittees. Within a short space of time an extraordinary amount of information was collected and digested, enabling the subcommittees to offer specific recommendations to the main Committee. A three-day session of the main Committee was recently held in New York where the Subcommittee reports were correlated and turned over to an Editorial Committee. It is the expectation within the course of a month or two, that industry will have the first tentative specification.

The forthcoming Bridge Specification of the AMERICAN WELDING SOCIETY will prescribe unit stresses varying with the range of stresses in a manner similar to those adopted in one or two European countries but expressed much more simply and in a manner that will lend itself readily to amendment when American fatigue testing produces more dependable data. Special credit is due to the Chairman of the Committee, individual members and chairmen of subcommittees. One prominent engineer has remarked that in all of his many years of technical committee work he has never known of such a tremendous volume of work accomplished in so short a time.

It is the opinion of Mr. F. H. Frankland, Technical Director of the American Institute of Steel Construction and Vice-Chairman of the Bridge Committee, that the rapid development in welding during the past four years makes it imperative to exercise sound engineering judgment and clear thinking when evaluating the information available. The fundamental principles of welding are such that there are no precedents that can be adopted from other forms of construction, and it therefore follows that creative originality and inventive genius are necessary in the engineer engaged in the design and construction of welded bridges.

There follows list of Committee personnel and names of the Subcommittees.

P. G. Lang, Jr., Chairman; F. H. Frankland, Vice-Chairman; Leon C. Bibber; A. W. Carpenter; O. J. Eidmann; LaMotte Grover (alternate); H. K. Ellis; G. D. Fish; A. L. Gemeny; O. L. Grover; S. C. Hollister; O. E. Hovey; Jonathan Jones; Ira D. S. Kelly; J. R. Lambert; F. P. McKibben; L. W. Millard; L. S. Moisseiff; H. H. Moss; N. R. Sack; D. B. Steinman; W. A. Stickel; Andrew Vogel; J. L. Vogel; W. G. Williams, Secretary; A. R. Wilson.

Sub-Committee No. 1 to Study and Obtain Copies of Existing Specifications, Codes and Papers That May Be of Use to Committee.

Sub-Committee No. 2 to Prepare Specifications on New Bridges.

Sub-Committee No. 3 to Prepare Specifications on Strengthening and Repair of Existing Bridges.

Sub-Committee No. 4 to Prepare Specifications on Technique and Equipment for Flame Cutting and Welding.

Sub-Committee No. 5 to Prepare Specifications for Methods and Procedure in Inspection.

Sub-Committee No. 6 on Recommendations Regarding A. A. S. H. O. Proposed Tentative Specifications for Welding Highway Bridges.

Sub-Committee No. 7 on Editing.

Value of Cooperation

In a report recently published in the Society JOURNAL it was stated by the author, a scientist who made a study of welding literature, that the AMERICAN WELDING SOCIETY'S publication contained 50 per cent more pertinent welding information than its nearest competitor, a German welding magazine. This we feel is an achievement of which the Society should be proud.

The success of the JOURNAL in its field has been made possible only because of the whole-hearted cooperation received from our various contributors. These include authors of papers, our technical committees that have furnished valuable reports, companies that have defrayed the cost of illustrations accompanying articles, our advertisers that have provided the wherewithal to make the publication possible and last, but not least, our Meetings and Papers Committee members that gave freely of their time and advice on the numerous details connected with the publication of a journal of this type.

At this time it gives us particular pleasure to express our deep appreciation to all that have cooperated toward the success of the JOURNAL. We want also to take this occasion to tender our thanks to our Directors, Divisional Vice-Presidents, Section Officers, Committee Members, Sustaining Members and the individual members for their support during the year. Permit us to extend seasonal greetings and best wishes for 1936.

M. M. KELLY
Secretary

Proposed Cooperation of Welding Interests

In recent interviews it has been forcibly brought to our attention that insufficient publicity has been given to the accomplishments of the AMERICAN WELDING SOCIETY in the advancement of welding, and what is at present being done to further that cause. For the benefit of those of the welding industry unfamiliar with the Society's work, we take this opportunity of describing, in as brief a manner as possible,

(*a*) The objects of the Society as stipulated in its Constitution.
(*b*) Some of the outstanding achievements of the Society.
(*c*) Some of the more important projects under way, and
(*d*) What further work could be undertaken toward the advancement of welding, if sufficient funds were available.

We will endeavor to depict these in the order mentioned.

Objects

These are very clearly defined in our Constitution and the promotional membership literature. As indicated, the Society's aim is to advance the Science and Art of Welding in a manner befitting a technical organization. By adhering strictly to these objectives, the Society has established itself, throughout this country and abroad, as the *authoritative body* and *spokesman* on all technical matters pertaining to welding.

Achievements

The Society has collected and disseminated authentic and up-to-date information on welding which has been placed

at the disposal of not only the manufacturing interests, but legislative bodies, governmental departments and other engineering societies, as well. This program has been carried out through Research, Standardization, Codes, Addresses, Meetings and the Society publication.

The amount of research work undertaken by the Society with its limited funds has far surpassed that of any organization of its size in the world. Of particular mention are those conducted in the Pressure Vessel, Street Railway and Structural Fields. These investigations resulted in obtaining reliable information upon which are based the welding codes and specifications.

Our welding codes are known and accepted everywhere. The most notable of these deal with buildings, piping, machinery and marine construction, storage tanks and sprinkler systems. Largely through the Society's efforts, welding is included in the building codes of several hundred cities and municipalities.

The Society has cooperated with other organizations in preparing safety codes so as not to unnecessarily hamper the use of welding. Through its cooperation with the American Society of Mechanical Engineers, the Boiler Code Committee has prepared rules covering welding of boiler drums and pressure vessels that have become law in a number of cities and municipalities, and in modified form, have been accepted by the U. S. Bureau of Navigation and Steamboat Inspection. Wherever possible codes appear in the name of the Society. In some instances, however, the Society is mentioned as a cooperating body, but in a number of these cases, the Society did the pioneer work and was largely responsible for the acceptance of welding.

In welding standardization the Society has been the leader. A few examples are—Standard Tests for Welds, Filler Metal Specifications, Nomenclature, Definitions and Symbols, Gages for Measuring Dimensions of Welding, Qualification Requirements for Welding Operators. Here again, the Society rendered aid to such technical bodies as the American Standards Association, American Society for Testing Materials, U. S. Bureau of Standards, Navy, Army, Bureau of Aeronautics, American Transit Association, A. S. M. E., A. I. E. E., American State Highway Officials and others. The complete list probably includes every organization that has had even the remotest interest in welding.

The maintenance of standards and procedure specifications is responsible to a considerable degree for the growth of welding during the past decade. These undoubtedly removed the doubt as to the quality of workmanship and increased confidence in welding on the part of engineers.

In the matter of publication, our Society ranks as the foremost authoritative source of real technical information. A survey recently completed by Professor M. Sayre of Union College, published in the August 1935 JOURNAL, indicates that the Society JOURNAL, over a given period, has published fifty per cent more articles containing real technical data than its nearest competitor, a German magazine.

In the educational field, the Society, with the cooperation of the Federal Board of Vocational Education, prepared training courses for oxyacetylene and electric arc welders which served as a guide to welding schools in laying out proper courses for training operators; also it prepared instruction manuals on Arc, Gas, Resistance and Thermit welding. Lecture courses have been conducted in several centers with success. Additional Sections have laid plans for a lecture series and the Society has appointed an educational committee to serve as a central coordinating committee in promoting and planning activities of an educational nature.

Projects Under Way

The Society continues to lead in the preparation of specifications and codes. Those under way include Highway and Railway Bridges, Railroad Rolling Stock and Appurtenances Thereto, Oil Storage Tanks, Marine Buoys, Design of Welded Penstocks, Revision of Building Code so as to permit higher stresses when using higher grade electrodes; Correlation of Code Requirements for Qualification of Welding Operators, Revision of Nomenclature, Definitions and Symbols and Filler Metal Specifications. Through its Conference Committee the Society is constantly rendering assistance to the A. S. M. E. Boiler Code Committee on its welding problems.

The Society's constant aim is to ascertain industry's need in the way of research, codes and standards. Symposiums, inspection trips and joint meetings are but a few of the ways in which this is accomplished.

A Handbook is in preparation which in every way will be comparable with the leading engineering handbooks in other fields. Recognized authorities will prepare chapters, and each chapter will be reviewed by five to fifteen competent experts. Funds have been obtained for going ahead with this book.

What Further Work Could Be Undertaken toward the Advancement of Welding, if Funds Were Available

In the matter of research work, unusual opportunity has been offered the welding industry by Engineering Foundation. An initial grant of $5000 has been made to start a comprehensive, coordinating research program, and for a review of the world's welding literature. Additional grants will only be made if the wholehearted cooperation of industry is forthcoming with adequate financial support.

The Society could, with additional technical assistance, collect and edit technical information; promote and correlate committee work and assist with the preparation of codes, standards and reports.

The Society could with additional funds, further promote the use of welding through a wide publicity campaign. It could expand its JOURNAL to include articles of popular appeal, news items and other departments.

Pressure Vessels

Lloyd's Register of Shipping, 17 Battery Place, New York, has recently issued specifications on "Tentative Requirements for Fusion Welded Pressure Vessels Intended for Land Purposes." This report covers Class I and II pressure vessels and includes information on material, welding, testing for each vessel and inspection. The report is available at $1.00 per copy.

The Great Lakes Exposition

The romance of the iron and steel industry will be the central theme of a great three-month industrial exposition to be held next year at Cleveland, Ohio, during July, August and September. The event will celebrate the centennial year of the city and is expected to draw large exhibits from industry in the Great Lakes region.

Men prominent in the steel and allied industries who are on the exposition organization committee include T. M. Girdler, Republic Steel Corporation; E. J. Kulas, Otis Steel Co.; H. G. Dalton, Youngstown Sheet & Tube Co.; Fred H. Chapin, National Acme Co.; Elton Hoyt, II, Pickands-Mather Co.; L. W. Greve, Cleveland Pneumatic Tool Co.; M. J. Van Sweringen and Alva Bradley.

The purpose of the exposition is to present a cross section of the industrial, commercial, cultural, educational and social life and progress of the Great Lakes area.

It is estimated that more than 25,000,000 people live within an easy day's drive of Cleveland and a minimum attendance of 4,000,000 at the exposition is expected.

An underwriting campaign for $1,000,000 is now in full sway and seems assured of success.

It is planned to present a constantly changing list of exposition entertainment attractions including athletic events, symphony concerts with famous soloists and guest conductors, fireworks, light operas, aquatic shows, championship swimming and diving contests and historical pageants.

Perkin Medal

The Perkin Medal of the Society of Chemical Industry will be presented to Professor Warren K. Lewis at a meeting of the Society on January 10, 1936, held jointly with the American Chemical Society. Professor Lewis is on the Faculty at the Massachusetts Institute of Technology. The award has been made in recognition of his creative activities as the father of modern chemical engineering and his training of and inspiration to many of the present and potential leaders in the profession. Professor Lewis will present a paper entitled "Application of Physical Data to High Pressure Processes." Dr. George A. Burrell of the Burrell-Mase Engineering Co. will speak on the subject of the Medalist and Professor Marston T. Bogert of Columbia University will make the presentation of the Medal. The meeting will be held at 7:45 P.M. at The Chemists' Club, 52 East 41st Street, New York City. A dinner will be held preceding the meeting, starting at 6:15 P.M.

SECTION ACTIVITIES

BOSTON

The next regular meeting will be held on Friday evening, December 20th, in Room 5-330, Mass. Institute of Technology, Cambridge, at 7:30 P.M. Mr. Charles H. Jennings, of the Westinghouse Research Laboratories in Pittsburgh, will speak on "Welding Problems in Large Structures."

A committee of three represented this Section at the Tenth Anniversary Conference of the New England Council, held at Hotel Statler on November 21st and 22nd.

CHICAGO

A meeting of the Chicago Section was held on Friday, November 22nd, in the Palmer House. The second of a series of lectures to be given through the fall and winter months was presented by Mr. Jules Muller on the subject "The Fundamentals of Metallurgy as Applied to Welding."

Mr. J. M. Jardine of the Western Welding and Boiler Repairing Co., presented a paper on "Welding in Structural Steel Repair and Modernization in the Chicago District," which was illustrated with slides.

A talk and demonstration of the air-acetylene flame applied to the brazing of pipes lip-joints, copper work, etc., was given by Mr. G. F. Goddeau, of Gasweld and Airway, Inc.

CLEVELAND

The first regular monthly meeting of the Cleveland Section was held at the Cleveland Engineering Society, Tuesday evening, November 26th. The speaker of the evening was Mr. J. F. Lincoln of the Lincoln Electric Company, whose subject was "Welding with the Heavy Coated Electrodes."

DETROIT

A joint meeting of the Detroit Sections of the AMERICAN WELDING SOCIETY, American Society of Mechanical Engineers and American Society for Metals was held on November 20th at the Fort Shelby Hotel. The speaker was Mr. J. J. Crowe, President, A. W. S., and Engineer in Charge of Research, Apparatus and Development of the Air Reduction Sales Co. His subject was "Flame Hardening and Machining with Oxyacetylene." The lecture was fully illustrated and samples were exhibited.

MARYLAND

The November meeting of the Maryland Section was held on the 22nd, at which there was an attendance of about 60 members and friends. Mr. William C. Stewart, Senior Metallurgist, Metallurgical Laboratory of the U. S. Naval Engineer Experiment Station, Annapolis, gave a very interesting and instructive talk, his subject being "What Do Weld Tests Prove?"

The next meeting of the Maryland Section will be held on Wednesday, January 22, 1936. The subject for this meeting will be "Demonstration of Stress Distribution in Welded Connections by Means of Photoelastic Apparatus."

MILWAUKEE

The November meeting of the Milwaukee Section was held on Friday, Nov. 8th at the Milwaukee School of Engineering. Mr. E. W. P. Smith, Consulting Engineer of The Lincoln Electric Co., gave a talk on "Applied Welding." Mr. K. Janiszewski, President of the Superior Steel Products Co., gave a talk on "Welding of Composite Dies."

The regular December meeting will be held at the Milwaukee School of Engineering on Friday, Dec. 6th, 8:00 P.M. The speakers for the evening will be Mr. John F. Risdon, Refinery Engineer, Texas Corp., whose talk will be "Welding as Applied to the Oil Industry." Also Mr. John B. Tinnon, Engineer, Metal & Thermit Corp., who will speak on "Thermit Welding of Rail Joints."

NEW YORK

The regular monthly meeting of this Section will be held on December 17th at 8:00 P.M., Engineering Societies Building, Room 502. The subject of the meeting will be "Stainless Steel and Aviation." Dr. W. M. Mitchell, Metallurgical Engineer, Subsidiary Manufacturing Companies, U. S. Steel Corp., will be the presiding officer.

Mr. Carl deGanahl, President, Fleetwings, Inc., will address the meeting on "Welding in Aviation." Mr. Virgil Whitmer, Republic Steel Corporation, will speak on "The Welding of Stainless Steel." A new four-reel sound motion picture will be presented through the courtesy of the Republic Steel Corporation.

The next meeting will be a joint meeting of the New York Section, A. W. S., and the Metropolitan Section, American Society of Mechanical Engineers, on January 21, 1936, Room 501, Engineering Societies Building. The subject will be "Pressure Piping."

PHILADELPHIA

An excellent meeting was held on November 18th. Mr. V. W. Whitmer of the Republic Steel Corporation, spoke on "Welding of Alloy Steels," which was very interesting. A lengthy discussion followed the conclusion of this address.

There will be no regular meeting in December except the Lecture Course meetings on the 4th and 11th.

At the January 20th meeting Dr. George V. Slottman, Applied Engineering Department, Air Reduction Sales Company, will present a paper on "Hydrocarbon Fuel Gases for Cutting."

PITTSBURGH

The November meeting was held on the 20th in the Roosevelt Hotel. Mr. W. D. Halsey, Assistant Chief Engineer, Boiler Division, Hartford Steam Boiler Inspection and Insurance Company, spoke on "Inspection of Welding." Mr. Halsey presented the latest ideas on the proper method of qualifying welding operators and also for the inspection of welds in pressure vessels and piping. Photographs of defective welds and lantern slides were shown.

EMPLOYMENT SERVICE BULLETIN

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V-62. Requirements for Associate Welding Metallurgist.

Training—Not less than four years' college work, preferably specializing in metallurgy.

Experience—A sufficient knowledge of metallurgy to assist in the development of methods for alloy steel welding and fabrication. A thorough knowledge and practical operating experience in the use of X-ray as a control and inspection method of casting production and as a means of welding control. A fundamental knowledge and practical experience with all types of welding. The ability to train X-ray and welding operators and supervise complicated welding procedures from a first-hand knowledge of shop welding practices.

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Hours—39 per week.

V-63. Wanted Sales Manager. To organize and direct the marketing of arc welding electrodes and equipment for nationally known company. Sales-Engineer, preferably college graduate, not over 42, with extensive selling experience and thorough practical knowledge. Applications will be held in strict confidence.

United States Civil Service Examinations

The United States Civil Service Commission has announced open competitive examinations as follows:

Engineering Draftsmen Positions

Applications for chief engineering draftsman, $2600 a year, and principal engineering draftsman $2300 a year (for work on ships), must be on file with the U. S. Civil Service Commission, Washington, D. C., not later than January 6, 1936.

The salaries are subject to a deduction of $3\frac{1}{2}$ per cent toward a retirement annuity. Optional branches are: Marine engines and boilers, and electrical (ship).

Certain education and experience are required.

Full information may be obtained from the Secretary of the United States Civil Service Board of Examiners at the post-office or customhouse in any city which has a post-office of the first or the second class, or from the United States Civil Service Commission, Washington, D. C.

Senior Chemist (Distillation)

Applications for the position of senior chemist (distillation) must be on file with the U. S. Civil Service Commission, Washington, D. C., not later than January 6, 1936. At present there is a vacancy in the Alcohol Tax Unit, Treasury De-

partment, which will be filled as a result of this examination.

The entrance salary is $4600 a year, subject to a deduction of 3½ per cent toward a retirement annuity.

V-65. Have opening for one or two young men around 30 to 35 years of age as servicemen. These men should have a good practical background in arc and gas welding and sufficient education and personality to make satisfactory contacts with customers.

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A-225. Acetylene welder and brazer. Experienced in experimental and research work, aircraft welding, auto repair, ornamental iron and job shop work.

Recent Progress in Welding Research

At the request of the Committee on Research of the American Institute of Electrical Engineers, the Technical Committee on Welding has made available to the members of the Institute a report with the above title. It was prepared collectively by the Fundamental Research Committee, a Committee of the AMERICAN WELDING SOCIETY of which Mr. H. M. Hobart is Chairman. The availability of this report is, therefore, due to the informal collaboration between several committees and societies.

The report, notwithstanding its length (nearly 100 typewritten pages plus a bibliography of about 280 references), is considered to be preliminary to a final report which it is anticipated will be a more critical review of the recent literature on research in the welding field. As much more work is necessary before this final revised report can be completed, a limited supply of mimeographed copies of the report in its present form has been prepared and copies may be had without charge by members of the A. I. E. E. and the AMERICAN WELDING SOCIETY (as long as the supply lasts) on application to Mr. H. H. Henline, National Secretary of the A. I. E. E., at 33 West 39th Street, New York, N. Y.

The report deals with *recent* researches on welding subjects and the references rarely relate to any publication of earlier date than 1933. The policy followed in preparing this compilation was to utilize the experience of specialists in each branch of welding and to include in the bibliography only those articles and papers which were considered by the specialists to be the most notable and valuable contributions to the literature of the subject.

Notwithstanding the recognized incompleteness of the report in its present form, it is believed that any approach to an equivalent is not yet available in any language and that, therefore, until the revision is completed, it will be of much value to welding specialists and others interested in the technical phases of welding and its applications.

WELDING NEWS

The Editor respectfully requests items of information to include in this department

Symposium on the Welding of Iron and Steel

A Symposium on the Welding of Iron and Steel was organized by the Iron and Steel Institute, 28 Victoria Street, London, S.W.1, and in cooperation with fifteen other institutions and technical societies, was held in London on May 2nd and 3rd. One hundred and fifty papers were presented. Two bound volumes containing a full account of the proceedings have now been published. They represent approximately 700 and 1000 pages of print and a large number of illustrations. These papers were written especially for the Symposium by leading experts of several countries. Discussions of the papers and authors' replies are included.

In view of the fact that only a limited number of copies will be printed, members of the AMERICAN WELDING SOCIETY desiring a copy should place their orders at once at the above address. The regular rate of these volumes is $11.00, but a special reduced price to members of our Society has been arranged at $8.00. It is, therefore, necessary in writing to mention that you are a member of the AMERICAN WELDING SOCIETY. The papers are divided as follows:

VOLUME I.

Group 1.—Present-Day Practice and Problems of Welding in the Engineering Industries.

Sub-Group (*a*).—Bridge and Structural Engineering, Pressure Vessels (including boilers, pipelines, tubes, tanks and vessels for use at high temperatures and pressures), Railway Material and Shipbuilding. (41 Papers.)

Sub-Group (*b*).—Aeronautical, Automobile, Chain, Electrical, Heavy Engineering and Machinery Manufacturing Industries (including Marine Engineering), and Iron and Steel Castings and Wrought Iron. (26 Papers.)

VOLUME II.

Group 2.—Welding Practice and Technique, including Welding Apparatus. (27 Papers.)

Group 3.—The Metallurgy of Welding. (29 Papers.)

Group 4.—Specification, Inspection, Testing and Safety Aspects of Welding. (27 Papers.)

Specification Documents for Building Materials and Construction

Classified and arranged by David H. Merrill, Assoc. Mem. Am. Soc. C. E. and Theodore C. Combs, Assoc. Mem. Am. Soc. C. E. 522 pages, cloth, $5.00, fabricoid leather, $7.50. Published for the Pacific Coast Building Officials Conference by R. C. Colling and Associates, Los Angeles.

Architects, engineers, contractors, building officials, and, in fact, all who have to do with the construction of homes or business and industrial buildings, bridges and highways, will find this book of unusual value.

It includes under one cover for the first time all specifications referred to in the Uniform Building Code under which 150 cities and counties in the United States operate. These documents are legally a part of the Code, and are required to be filed with city or county clerk. Until now they have been found only in pamphlet form separately and several only in typewritten or mimeographed sheets.

"Specification Documents" contains 63 standard and tentative specifications and test programs compiled from many sources, classified and arranged for ready reference. Nearly every major engineering and technical society has assisted in their preparation. The publishers mention among the sources the following: American Society for Testing Materials; American Concrete Institute; National Fire Protection Association; National Board of Fire Underwriters; Underwriters' Laboratories, Inc.; AMERICAN WELDING SOCIETY; American Wood Preservers Association; U. S. Department of Commerce, Bureau of Standards; American Institute of Architects; American Society of Mechanical Engineers; American Society of Refrigerating Engineers; and the Research Department of the Pacific Coast Building Officials Conference.

The text of "Specification Documents" is amplified by many drawings and illustrations. The book is so bound that it will open flat at any page.

Available on order from Pacific Coast Building Officials Conference, 124 West 4th St., Los Angeles, California.

Eleventh Annual Conference on Welding, Purdue University, Held on December 5–6, 1935

December 5th

Forenoon

9:00 A.M.—Registration Opens — Michael Golden Shops

Exhibits Open—Corridor, Michael Golden Shops

10:00 A.M.—Announcements

10:30 A.M.—New Equipment and New Processes in the Welding Field. Brief statements by companies represented by Exhibits and Demonstrations

11:30 A.M.—Exhibits and Demonstrations

Afternoon

1:15 P.M.—Exhibits and Demonstrations

2:00 P.M.—Resistance Welding

L. H. Frost, Welding Engineer, Electric Controller and Manufacturing Company, Cleveland

Types of Controls Used in Resistance Welding, F. H. Roby, Engineer, Square D Company, Milwaukee

Shop Costs in Job Welding, L. C. Monroe, Editorial Staff, The Welding Engineer, Chicago

4:00 P.M.—Exhibits and Demonstrations

Evening

7:00 P.M.—Action of A.C. and D.C. Arc—Slow Motion Movie Showing Comparison of Magnetic Flow Effect, W. M. B. Brady, Arc Welding Specialist, General Electric Company, Chicago

8:00 P.M.—Application of the Metal Spray (Talk and Demonstration), K. D. Falk, Regional Manager, Metal Spray Company, Inc., Chicago

December 6th

Forenoon

8:00 A.M.—Exhibits and Demonstrations

9:00 A.M.—The Allocation of Various Welding Rods to Types of Work, Jules Muller, Consulting Engineer, Chicago Steel and Wire Company, Chicago

Increasing Business with New Lines and New Work, W. J. Volpert, State Secretary, Indiana Ironsmiths and Welders, Peru

Procedure for Manganese Steel Welding, E. L. Quinn, Welding Engineer, American Manganese Steel Company, Chicago Heights

11:00 A.M.—Exhibits and Demonstrations

Afternoon

1:15 P.M.—Exhibits and Demonstrations

2:00 P.M.—The High Voltage Welding of Copper, W. C. Swift, Service Engineer, American Brass Company, West Alexandria, Ohio

The Welding of Stainless and High Tensile Low Alloy Steels, T. R. Lichtenwalter, Metallurgical Department, Republic Steel Corporation, Massillon, Ohio

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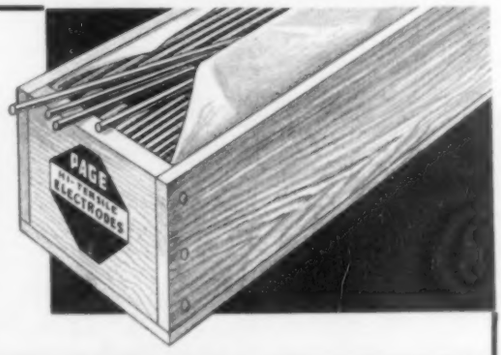

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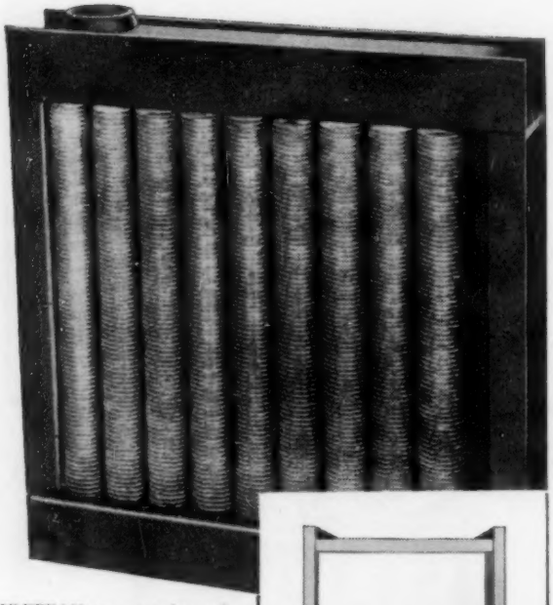
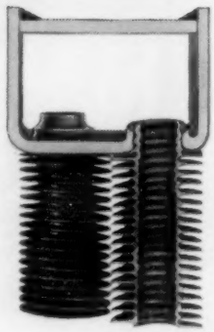


UNIFIN Heater, manufactured by the Canada Vulcanizer and Equipment Co., Limited, of London, Ont. Copper tubes and steel structional members are Tobin Bronze Welded.



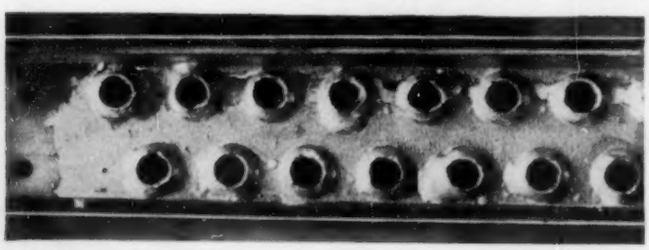
Cross section of the Tobin Bronze Welded "UNIFIN" Heater.

THE Canada Vulcanizer and Equipment Co., Limited, of London, Ont., manufactures unit heater elements and blast heaters. In the construction of the Unifin Heater, the one-piece "All-In-One" finned copper tubes are welded into the steel channel header with Tobin Bronze*. The steel top plate, enclosing the header, is likewise welded with Tobin Bronze. Welds are made quickly, and the resulting joints are strong, leak-proof, and uniformly dependable.

Tobin Bronze, with its high tensile strength, toughness, durability and uniform composition, frequently proves the quickest, surest, and most economical method of assembly. This time-tried welding rod is widely accepted as the ideal material for the production and repair welding of cast and malleable iron, steel and copper parts and equipment. Its low melting point of 1625°F. saves preheating, time and gas, and reduces the possibility of warping or cracking the parts. Be sure the bronze rod used for acetylene welding in your shop has the word "Tobin" stamped in the metal.

Tobin Bronze and sixteen other Anaconda Welding Rods are described in detail in Anaconda Publication B-13. This *new* 24-page booklet will be mailed to you free on request. Included also in this publication are recommended procedures for high voltage carbon arc welding of copper and copper alloys. Be sure to write for your copy.

*Reg. U. S. Pat. Off.



Finned copper tubes welded to channel steel header with Tobin Bronze.

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ANACONDA WELDING RODS

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An Investigation of Welded Seat Angle Connections†

By INGE LYSE* and NORMAN G. SCHREINER**

Preface

The rapid advance of the process of welding in steel construction has brought forth a number of interesting research problems. One of these problems relates to the shelf-angles that are commonly used in structural practice. From an economic view-point it is desirable to know the minimum size of weld made necessary by the respective requirements of vertical shear and of bending, the bending being affected by the nature and position of the load.

This question is answered in the series of investigations conducted by the Structural Steel Welding Research Committee of the American Bureau of Welding in cooperation with the Fritz Engineering Laboratory of Lehigh University. An interesting by-product is the indication of the advantage of rolling large radius fillets on the steel shelf angles themselves.

The cooperative arrangement made between the Committee and Lehigh University illustrates the excellent work that can be done in a university laboratory under the guidance of a technical committee. Perhaps of equal importance is the familiarizing of young student engineers with the possibilities of welding and its various applications.

LEON S. MOISSEIFF, *Chairman*,
Structural Steel Welding Committee

Synopsis

THE following report presents the results of tests of twenty-nine welded seat angle test specimens and the correlative tests of four full-size beam-column connections. The test specimens consisted of two angles welded along the ends of their vertical legs to either side of a plate. The load was applied at three different positions on the outstanding leg. The full-size connections were built up of stub columns with the seat angles welded thereon in the manner described above, and a 20-in. I-beam supported on the outstanding legs. The I-beam was held in place by tack welds or bolts between the flange and the outstanding leg.

The results of the investigation show the effect of the thickness of the angle, the location of the resultant reaction of the beam, the length of the vertical leg of the angle and the strength of the weld on the strength of the seat angle connection. The high concentration of stress at the end of the beam and its effect upon the effective lever arm are pointed out. In general, the failure of this type of connection was gradual and would cause excessive deflection of the beam rather than a collapse of the structure. Since the tests were stopped slightly beyond the load required to fracture the weld at the heel of the angle, the recorded load is not the maximum that this connection can carry, but may be defined as the maximum that can be carried without excessive deflection.

The analysis of the results is the basis of the recommendations for the design of angles, welds and beams presented in the last section of this paper.

† Report to Structural Steel Welding Committee, A. B. W., presented at Fall Meeting, A. W. S., Oct. 1934.

* Research Associate Professor of Engineering Materials, Lehigh University, Bethlehem, Pa.

** American Bureau of Welding Research Fellow, Lehigh University, Bethlehem, Pa., in immediate charge of Seat Angle Investigation.

I. Introduction

1. *Acknowledgment.*—This investigation was carried on as one of the projects of the Structural Steel Welding Committee of the American Bureau of Welding in cooperation with Lehigh University, using the facilities of the Fritz Engineering Laboratory. The steel necessary was furnished through the courtesy of the Bethlehem Steel Company and all fabrication was done in the university shop. Acknowledgment is made to all members of the Structural Steel Welding Committee for their many helpful suggestions and criticism and particularly to the Chairman, Mr. L. S. Moisseiff, Messrs. E. H. Ewertz, H. H. Moss, H. M. Priest and W. Spraragen. Acknowledgment is also due to Mr. C. H. Mercer, Consulting Engineer, McClintic-Marshall Corporation and Mr. V. E. Ellstrom, Manager of Sales Engineering, Bethlehem Steel Company, for furnishing the structural steel, to Mr. C. C. Keyser, Assistant in the Fritz Engineering Laboratory and Professor C. D. Jensen of the Department of Civil Engineering for their valuable assistance and cooperation, to Professor J. B. Reynolds of the Department of Mathematics for assistance in the theoretical analysis, and to Mr. D. M. Stewart, Research Fellow in Civil Engineering for the supplementary studies by means of photoelasticity.

2. *Purpose of the Investigation.*—The investigation of welded seat angles was made in order to obtain experimental information from which a rational theory of design could be evolved for their economic use in welded structures. In general, seat angles are used in two ways in structures:

(*a*) As an erection seat, for the purpose of supporting the end of the beam during erection and prior to the attachment of the web angles which carry the end reaction.

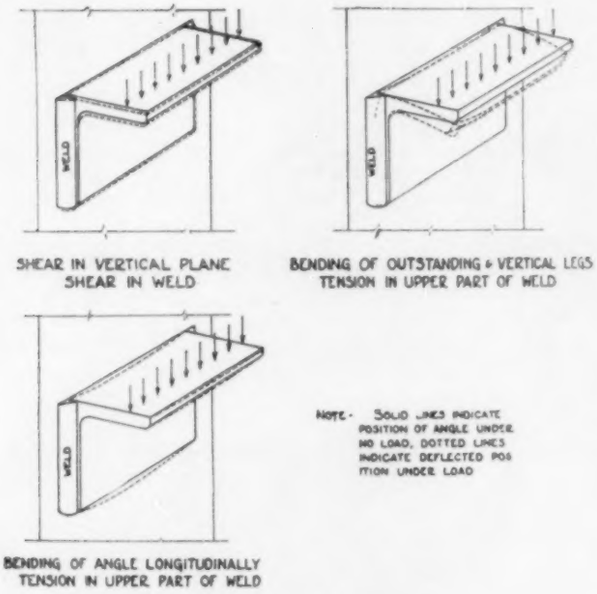

WELD
SHEAR IN VERTICAL PLANE
SHEAR IN WELD
WELD
BENDING OF OUTSTANDING & VERTICAL LEGS
TENSION IN UPPER PART OF WELD
WELD
NOTE - SOLID LINES INDICATE POSITION OF ANGLE UNDER NO LOAD, DOTTED LINES INDICATE DEFLECTED POSITION UNDER LOAD
BENDING OF ANGLE LONGITUDINALLY
TENSION IN UPPER PART OF WELD

Fig. 1—Illustration of the Seat Angle Problem

Used in this way, the strength needs only be sufficient to preclude construction failure or damage in transit.

(*b*) As a load carrying member, transferring the end reaction of the beam to the column. Used thus, the beam which they support must be held against lateral as well as vertical displacement. If the beam supports a rigid flooring, such as a concrete slab, it may be considered as adequately supported laterally. However, if the beam supports a more flexible floor or is a member of an open framework, lateral support is necessary. This may be accomplished by the use of a top angle or web angles, neither of which is considered as carrying any of the vertical load.

II. General Statement of the Problem

While there are many varieties of beam seats, and structural welding engineers are designing new types whenever the opportunity presents itself, this investigation has been confined to the simplest possible type, and the one most widely used at present, namely, a simple angle seat welded to the column by means of vertical fillet welds at each end of the vertical leg. The lower flange of the supported beam may be welded or bolted to the outstanding leg of the angle. This type of beam seat is also in common use in riveted structures, and the results of this investigation apply equally well to these angles, if necessary corrections due to the different manner of attachment to the column are made.

The problem of this welded seat angle type of connection is illustrated in Fig. 1, and may be divided into three parts.

(*a*) Owing to the reaction of the load on the angle, there is a vertical shear imposed on the weld causing a downward deflection.

(*b*) Owing to the moment *Wa* (see Fig. 2), the outstanding leg bends downward and the vertical leg bends away from the column at the heel of the angle. This action of the vertical leg produces a corresponding compressive reaction toward the toe of this leg of the angle. The existence of a compression between the back of the vertical leg and the face of the column introduces an upward frictional force which offsets part of the vertical load and reduces the downward deflection due to the vertical shear strain in the weld. For a short distance from the ends of the angle, the weld restrains the vertical leg from bending outward. It follows that there is a warping of the surfaces of the angle.

(*c*) The angle acts as a short, stubby beam, elastically restrained at the ends by the weld. This action causes a greater deflection at the center than at the ends and further modifies the shape of the outstanding leg.

The beam flanges which are supported by the angle bend under the reaction and cause the reaction to be concentrated on an area under the web. The amount of this bending is determined by the relative stiffness of the flange and the outstanding leg. Since the flanges are also fastened to the outstanding leg, the two act more or less as a unit and the state of stress in the outstanding leg is thereby affected.

The stress condition in the weld itself is rather complex consisting of a combination of vertical shear and bending in two directions. The vertical shearing stress is of small importance except in certain combinations of sizes of angle and weld. Ordinarily the determining factors are the stresses set up by the bending moments.

III. Test Program

1. The test program as approved by the Committee consisted of two types of specimens designated as Series A and Series B. Series A was designed to permit the study of each variable in turn at a minimum of expense, while Series B consisted of full-size beam-column connections, permitting the correlation of the results on the

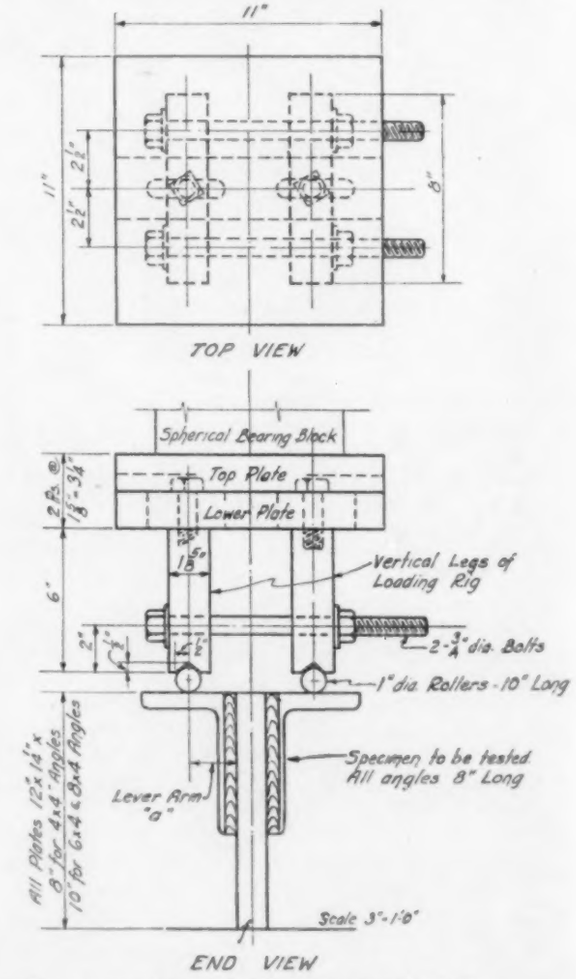


FIGURE 2 SERIES "A" SPECIMEN & LOADING RIG.

Series A specimens with those obtainable in actual practice. Series A consisted of twenty-nine specimens, Series B of four specimens.

(*a*) *Series A*—a simple, balanced test specimen was prepared as shown in Fig. 2 consisting of a central plate, on either side of which the angles were welded, care being taken to place them directly opposite each other. The load was applied through rollers symmetrically placed on each angle, thus avoiding the necessity of taking care of any eccentricity.

(*b*) *Series B* consisted of a 20-in. loading beam (I 20a, 81.4 lb.) 18 ft. $^1/_2$ in. long, resting on seat angles 8 in. long, which in turn were welded to stub columns made up of 10-in. H-sections (B10b, 54 lb.) 12 in. long. Figure 3 shows the details of the end connections and gage points, and Fig. 4 shows a specimen ready for test. The lower flange of the beam was welded or bolted to the outstanding leg of the angle.

(*c*) *Welding.*—The welding was performed in the laboratory shop under direct supervision. The operator passed the qualification tests of the Structural Steel Welding Committee, American Bureau of Welding. The welding electrode for the major part of the investigation was a lightly coated electrode, conforming to A. W. S. Specification Class E40[1] of $^5/_{32}$-in. and $^3/_{16}$-in. diameter. The D.C. arc characteristics were, voltage 17 to 19, amperes 165 to 200, dependent on the electrode diameter and size of the work. The average strength of the standard $^3/_8$-in. end-fillet welded qualification specimen was 13,250 lb. per lin. in., corrected for over-sized dimensions. The required average strength per lin. in. was 12,000 lb.

Heavily coated electrodes $^3/_{16}$ in. in diameter of several commercial types were also used. D.C. arc characteristics were voltage 35, amperes 220. The average strength of the standard $^3/_8$-in. end-fillet welded qualification specimen was 16,390 lb. per lin. in. The ductility, as determined by the free-bend test, ranged from 20 to 34 per cent.

The use of heavier bars in this type of qualification specimen seems advisable in order to produce failure in the weld directly, rather than a secondary failure due to excessive yielding of the parent metal. This is especially desirable on the specimens in which heavily coated electrodes are used.

Where multi-layer welding was specified the previous layers were carefully cleaned of scale by means of a stiff wire brush and file before adding the next layer.

The welds were carefully gaged and without exception were within the designed limits of minus 0, plus $^1/_8$ in. A rigid specification and procedure control was laid out and followed, in consequence of which uniform results were obtained. Some difficulty was encountered in obtaining proper fusion between the heel of the angle and the plate, but failure specifically due to improper fusion at this point occurred in only three welds.

(*d*) *Angles.*—The angles were of stock size, cut on a power saw to a length of 8 in. $\pm$ $^1/_{16}$ in. The outstanding leg in all cases was 4 in.; the vertical leg was 4, 6 or 8 in. The thickness varied from $^1/_2$ in. to 1 in. The angles were clamped to the plate preparatory to welding, care being taken so that the outstanding legs were parallel to the bearing edge of the plate.

(*e*) *Specimen Nomenclature.*—In designating the specimens, a combination of letters and numbers was used as follows:

Specimens of Series A used the series letter followed by four numbers for identification, those of Series B used the series letter followed by three numbers. For example, in the symbol A 444-2:

First, letter A indicated the series to which the specimen belonged.

[1] A. W. S. Specifications for Filler Metal (Revised June 1, 1933).

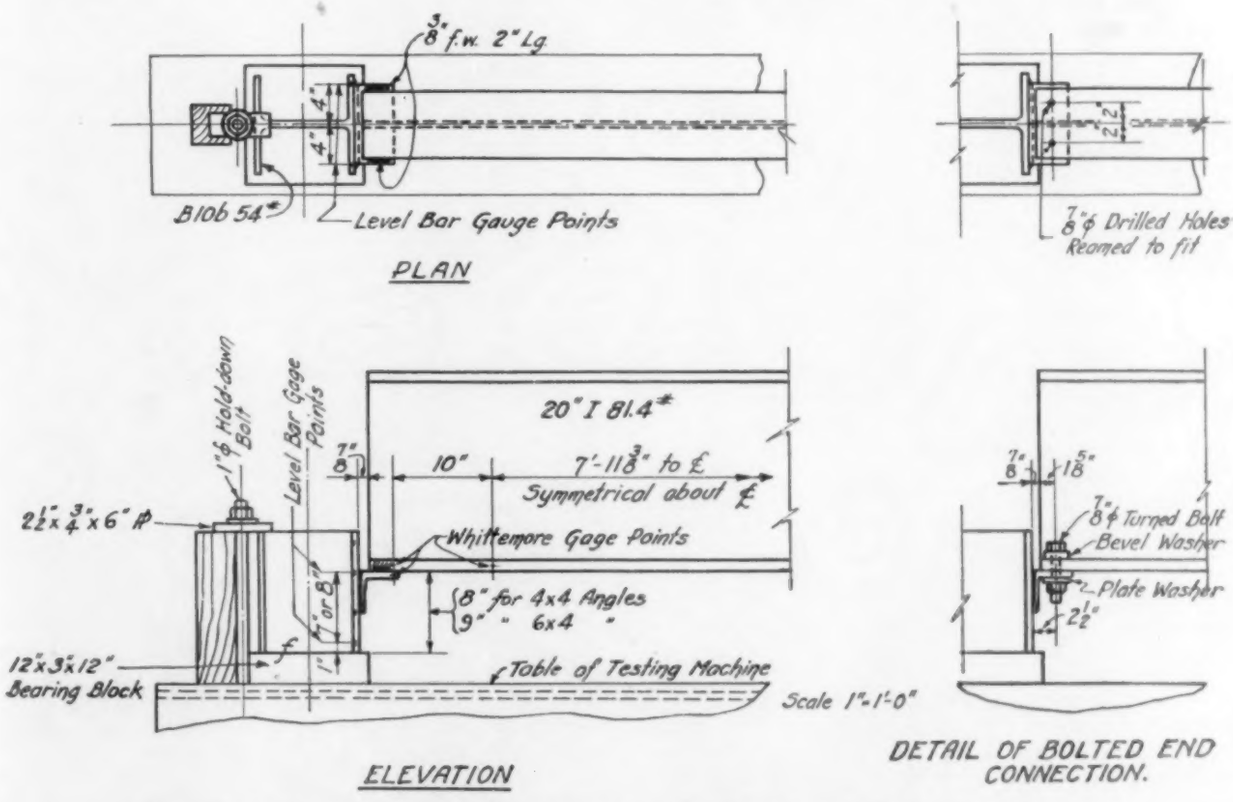


FIGURE 3. DETAILS OF END CONNECTION AND GAGE POINTS - SERIES B.

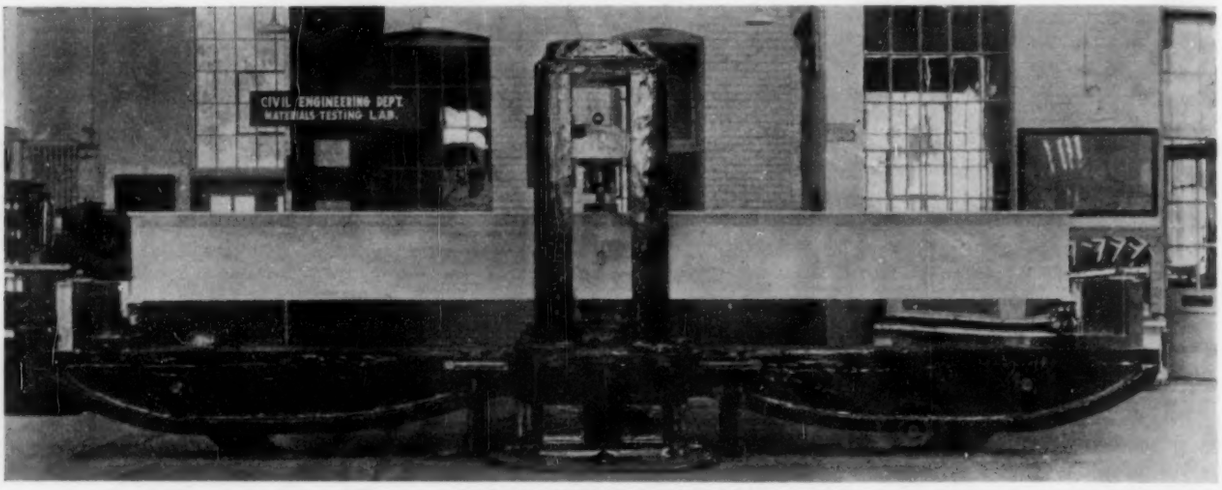


Fig. 4—Series B Specimen Ready for Testing

First numeral 4 indicated the length of the vertical leg of the angle in inches.

Second numeral 4 indicated the thickness of the angle in eighths of an inch.

Third numeral 4 indicated the size of the fillet weld in eighths of an inch.

Second letter, if used, indicated special points of difference from the general type as explained in notes accompanying the data.

Last numeral 2 indicated the lever arm at which the test was made, 1 indicating a 1.2-in. lever arm while 2 and 3 indicate 2.0-in. and 3.0-in. lever arms, respectively. This final figure was omitted in the specimens of Series B since the exact location of the resultant load was unknown. In this paper, the term lever arm will signify the distances from the back of the angle to the point of application of the load and will be designated by "*a*" (see Fig. 2).

2. *Factors Studied.*—The following factors affecting the behavior of the connection were studied:

(*a*) Effect of the lever arm of the load, in both longitudinal and lateral directions.

(*b*) Effect of the thickness of the angle.

(*c*) Effect of the length of the vertical leg of the angle.

(*d*) Effect of the size of the wled.

(*e*) Effect of the type of welding rod.

(*f*) Location of the reaction of the beam on the seat angle.

3. *Description of Loading Rig and Gaging Devices.*—(*a*) *Series A.*—The specimens of Series A were tested in the 300,000-lb. or the 800,000-lb. capacity testing machines in the Fritz Engineering Laboratory. The load was applied through an adjustable loading rig shown in Fig. 2, consisting of a top section of two steel plates, the top one of which was channeled to clear the bolt heads. The lower plate was slotted along the center line to provide easy adjustment of the vertical legs on which it rested. The vertical legs were held in any desired position by means of cap bolts passing through these slots into tapped holes in the vertical legs. The load was applied by the head of the machine through a spherical bearing block resting on the top plate.

The method of holding the 1-in. diameter rollers through which the load was applied was changed three times as requirements indicated. In the first type, Fig. 5, used only on Specimen A 443-1, the bottom of the vertical legs of the loading rig were plane and rested on the rollers, which were thus nearly free to roll, being restrained only by light spring steel fingers. Owing to the outward deflection of the angle, the secondary horizontal force pulled the vertical legs of the loading rig apart, thus increasing the lever arm. To correct this defect two $^{3}/_{4}$-in. diameter bolts were introduced, as shown in Fig. 6, to hold the vertical legs of the loading rig in position until the welds fractured. After this occurred the deflection of the outstanding legs increased materially and the bolts generally yielded slightly. The maximum increase in lever arm due to this effect averaged nine per cent at final load, with a maximum increase of sixteen per cent in the case of Specimen A 864-1. Below the load at which the weld fractured the nominal lever arm was maintained within the limits of observation. In this set-up the rollers were still nearly free to roll and the horizontal restraining force on the outstanding leg of the angles was considered negligible. This type of loading was used on Specimens A 443-2, A 443-3, A 444, A 643, A 654 and A 444a.

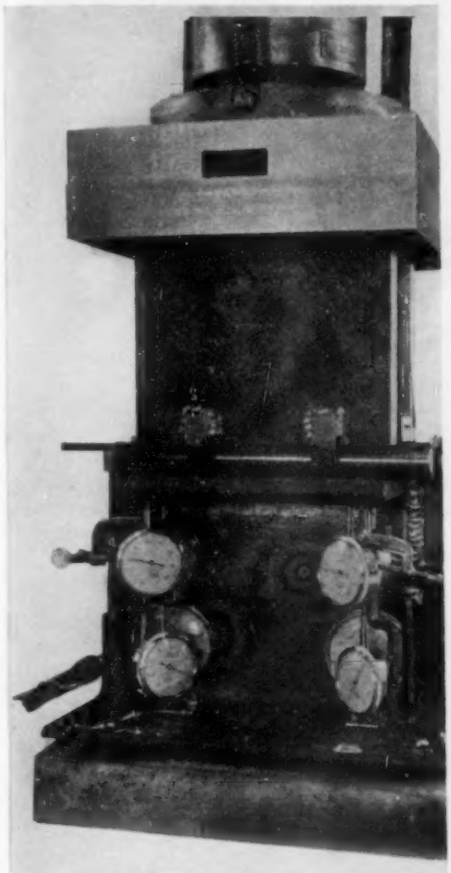
In the third set-up, the rollers were restrained in V's cut in the bottom of the vertical legs as shown in Fig. 6. This construction prevented the rollers from moving laterally and introduced a horizontal restraining force counteracting the tearing effect at the top of the weld. This type of loading rig was used on all the remaining specimens of Series A.

The load was applied over the full 8-in. length of the angle in all specimens except A 644X-1 and A 644Y-1 where the loading was through rollers 1 in. and 3 in. long, respectively. These rollers were centered longitudinally on the outstanding leg and observations were made at 3.0, 2.0 and 1.2-in. lever arms.

(*b*) *Observations.*—Measurements of the downward deflection of the outstanding leg were taken at measured intervals by two groups of four Ames dials, each group on gage lines 1 in. in from each end of the angle. The plungers of the dials were extended as necessary by means of hardened steel pins. The two dials closest to the vertical leg read to 0.0001 in. while the outer two dials of each group were graduated to only 0.001 in. Figure 5 shows the arrangement of these dials.

Tensile strains in the top end of the welds were measured with Huggenberger Tensometers using the $^{1}/_{2}$-in. gage length on Specimens A 444, A 444a, A 643, A 644 and A 654. The weld was first piled up slightly during fabrication and then filed off flush with the outstanding legs of the angle. One knife edge of the tensometer was set on the weld metal and the other on the plate, the $^{1}/_{2}$-in. gage length being divided equally between the weld and the plate.

Fig. 5—Side View of First Loading Rig and Ames Dials



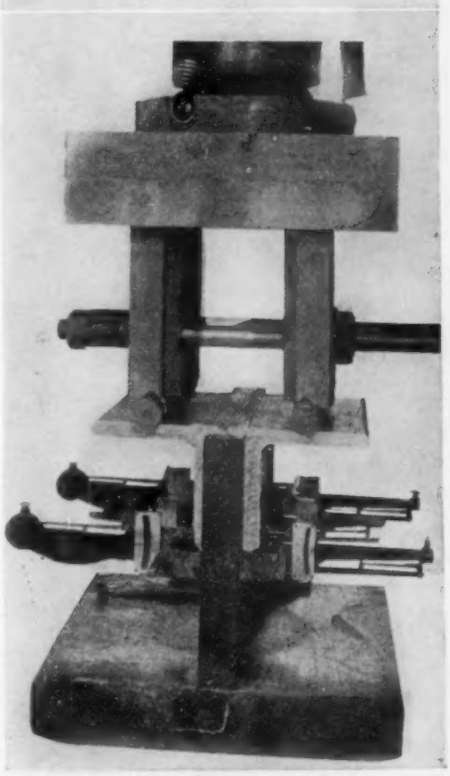
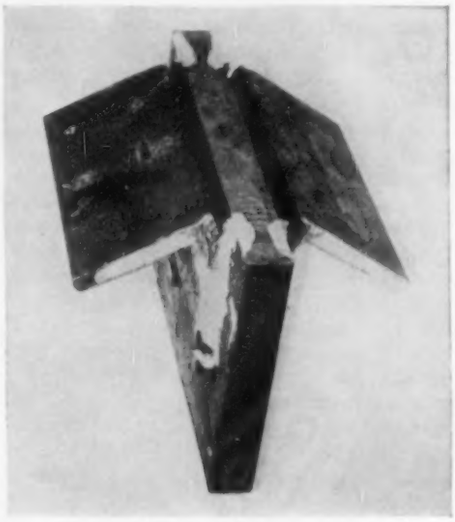


Fig. 6—End View of Final Loading Rig Showing Bolts Restraining the Vertical Legs and U-Grooves

Five tensometers equally spaced along the toe of the vertical leg of the angle measured the downward deflections of the angle with respect to the plate. Figure 6 shows a set-up ready for testing with tensometers on both angles. In most tests the groups of Ames dials were placed on one test angle and the five tensometers on the opposite angle.

Fig. 7—Typical Specimen at Completion of Test — Specimen A 443-2



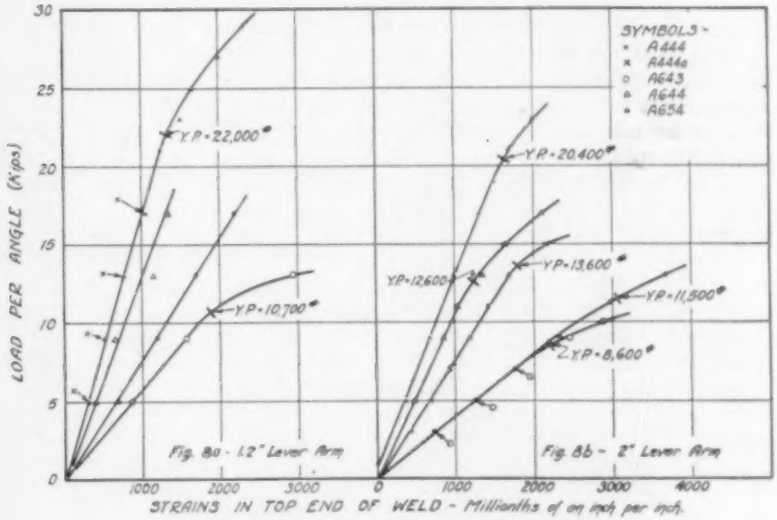


FIGURE 8. LOAD-STRAIN DIAGRAMS FOR WELDS.

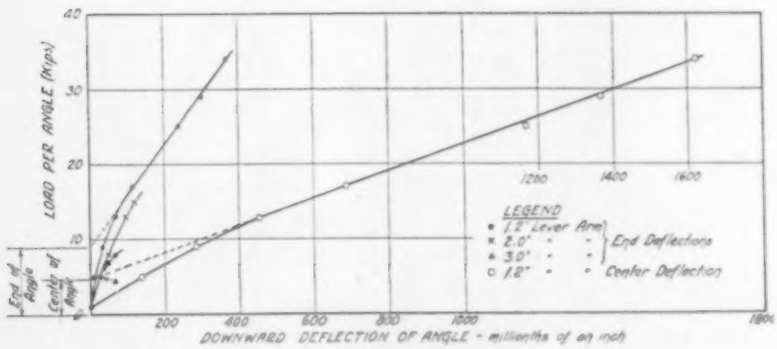


FIGURE 9 LOAD-DOWNWARD DEFLECTION CURVES TYPICAL FOR BOTH SERIES OF TESTS

(*c*) *For Series B* the 20-in. I-beam was loaded at the quarter points. A set of Ames dials measured the downward deflections of the outstanding leg of one of the test angles and five tensometers measured the total downward deflections of the other test angle. Strains in the beam flange and slip between the test angle and the beam end were measured on both sides of each end over a 10-in. gage length with a Whittemore strain gage reading to 0.0001 in. The deflection of the beam at the center was measured by the mirror, scale and wire method. The tilting of the columns was measured by means of a level bar of 3-in. base line at six-gage points on the back of the column flange.

In both series of tests the specimens were completely coated with a thin mixture of hydrated lime and water in order to better observe strain lines and cracking.

4. *Test Procedure.*—(*a*) *Series A.* Complete observations were taken at three lever arms on each specimen, namely, 3.0, 2.0 and 1.2 in. in succession, up to the yield point of the specimen as determined by disproportionate deflection and/or by cracking or scaling of the whitewash. The load was applied at a head speed of 0.05 in. per minute. The increments of load were such that approximately six points would be obtained below the yield point. In the case of the 3-in. and 2-in. lever arms, the load was slowly released after the yield point was reached and the rollers were moved in to the next shorter lever arm. In the case of the 1.2-in. lever arm the instruments were removed after the yield point was reached and the load continuously applied until the conclusion of the test. Observations were made of the scaling of the whitewash on the angle and welds and of the cracking of the welds at the top end. The test was concluded when the specimen refused to take any further load without excessive deflection, at which time the heel of the angle had generally been bent away from the plate approximately $^3/_8$ of an inch. Final observations were made as to the location of the rollers, and the general appearance of the welds and angle.

(*b*) *Series B.* Readings on the instruments were taken from an initial load in small increments up to the final load. The speed of the head of the machine was 0.05 in. per minute. Observations were made with respect to scaling of the whitewash in any part of the specimen with particular attention paid to the behavior of the welds.

Table 1—Physical Properties of Steel in the Seat Angles

Size of Angle In.	Yield Point Lb./In.²	Ultimate Strength Lb./In.²	Per Cent Elongation in 2 In.	Per Cent Reduction of Area	Modulus of Elasticity Lb./In.²
(1)	(2)	(3)	(4)	(5)	(6)
4 × 4 × $^1/_2$	32,400	58,510	37.0	69.3	29,650,000
Piece 2	40,260*	62,560	..	..	28,330,000
4 × 4 × $^3/_4$	35,750	64,700	38.0	62.0	28,500,000
6 × 4 × $^1/_2$	37,105	62,075	36.1	66.3	29,075,000
6 × 4 × $^5/_8$	33,500	56,650	34.5	67.9	29,000,000
6 × 4 × $^3/_4$	32,175	63,225	37.5	62.0	28,730,000
8 × 4 × $^1/_2$	41,460	66,800	32.0	60.5	29,100,000
8 × 4 × $^3/_4$	32,450	57,415	40.8	67.0	29,250,000
8 × 4 × 1	32,000	60,780	40.6	65.3	29,000,000

* Used for Specimens A 444C-1, B 444 and B 444B.

IV. Test Data

1. *Physical Properties of Materials.*—Two tensile specimens were cut from each angle used in the investigation, and observations made of the yield point as determined by the drop of the beam, ultimate strength, elongation in 2 in., reduction in area and modulus of elasticity in accordance with A. S. T. M. Specification A9-33. The results are presented in Table 1. Each value is the average of the two specimens mentioned above. The yield-point stress varied from 32,000 to 41,460 lb. per sq. in. and the ultimate strength from 56,650 to 66,800 lb. per sq. in.

2. *Seat Angle Tests.—Series A.* (*a*) The size and make-up of the test specimens are shown in Table 2, columns 2 to 5, inclusive. The test results are given in the remaining portion of the table. All these specimens

Table 2—Test Results of Series A Specimens

Specimen No.	Size of Angles In.	Weld Data: Fillet Size In.	Weld Data: Total Length In.	Lever Arm at Failure In.	Load per Angle (Lb.): Scaling of Fillet of Angle	Load per Angle (Lb.): Scaling at Top End of Weld	Load per Angle (Lb.): Crack in Top End of Weld	Load per Angle (Lb.): Final Load
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
A 443–1	4 × 4 × $^1/_2$	$^3/_8$	8	1.2	29,950	28,550	29,325	30,430
2	4 × 4 × $^1/_2$	$^3/_8$	8	2.0	16,800	21,000	22,225	31,250
3	4 × 4 × $^1/_2$	$^3/_8$	8	3.0	10,400	12,350	13,470	13,470
A 444–1	4 × 4 × $^1/_2$	$^1/_2$	8	1.2	.....	32,000	39,000	39,380
2	4 × 4 × $^1/_2$	$^1/_2$	8	2.0	18,850	18,500	24,000	24,000
3	4 × 4 × $^1/_2$	$^1/_2$	8	3.0	10,100	10,000	11,250	13,840
A 463–1	4 × 4 × $^3/_4$	$^5/_8$	8	1.2	71,000	89,500	100,000	112,250
A 464–1	4 × 4 × $^3/_4$	$^1/_2$	8	1.2	73,000	91,000	101,000	133,835
A 466–1	4 × 4 × $^3/_4$	$^3/_4$	8	1.2	67,500	116,250	176,500	185,500
A 643–1	6 × 4 × $^1/_2$	$^3/_8$	12	1.2	.....	33,800	38,550	41,650
A 644–1	6 × 4 × $^1/_2$	$^1/_2$	12	1.2	37,000	40,500	46,000	67,305
X–1	6 × 4 × $^1/_2$	$^1/_2$	12	1.2	22,250	40,500	44,150	67,500
Y–1	6 × 4 × $^1/_2$	$^1/_2$	12	1.2	25,800	40,800	43,700	78,000
A 654–1	6 × 4 × $^5/_8$	$^1/_2$	12	1.2	53,675	60,550	74,700	98,300
A 655–1	6 × 4 × $^5/_8$	$^5/_8$	12	1.2	57,000	84,500	102,000	116,000
A 664–1	6 × 4 × $^3/_4$	$^1/_2$	12	1.2	100,000	100,500	136,300	183,200
A 843–1	8 × 4 × $^1/_2$	$^3/_8$	16	1.2	49,000	53,000	74,350	98,375
A 844–1	8 × 4 × $^1/_2$	$^1/_2$	16	1.2	53,000	63,000	74,030	82,050
A 864–1	8 × 4 × $^3/_4$	$^1/_2$	16	1.2	87,250	112,500	132,000	174,100
A 884–1	8 × 4 × 1	$^1/_2$	16	1.2	137,500	145,000	164,500	204,000
2	8 × 4 × 1	$^1/_2$	16	2.0	55,000	84,000	120,500	140,150
3	8 × 4 × 1	$^1/_2$	16	3.0	36,150	48,000	51,450	63,175
A 886–1	8 × 4 × 1	$^3/_4$	16	1.2	137,500	145,000	170,000	230,900
A 444a–1	4 × 4 × $^1/_2$	$^1/_2$	4	1.2	.....	35,900	45,800	52,230
A 444C–1	4 × 4 × $^1/_2$	$^1/_2$	8	1.2	37,000	43,500	75,000	75,000
A 644C–1	6 × 4 × $^1/_2$	$^1/_2$	12	1.2	37,000	46,300	54,150	81,000
A 644D–1	6 × 4 × $^1/_2$	$^1/_2$	12	1.2	35,100	38,000	52,500	69,000

were welded with a lightly coated electrode, known to welders as "bare wire" except A 444C-1, A 644C-1, A 644D-1, which were welded with a heavily coated electrode. Specimen A 444a-1 was made up with only a short length of weld on either end of the angle.

(*b*) At this point it is well to describe the general procedure of observation. As mentioned previously the instruments were removed shortly after the deformations became disproportionate to the load increments, and either the loading rig was adjusted to the next succeeding test (that is, from 3.0 to 2.0 or from 2.0 to 1.2-in. lever arm) or the loading was continued to the completion of the test. The first observation was a scaling of the whitewash on the fillet of the angles starting in the center but soon scaling over the full length. The loads at which this scaling took place are noted in column 6, Table 2. The load on the angle could then be increased approximately seventeen per cent when scaling of the whitewash on the top end of the welds would next be observed, generally on one of the welds only, but often this scaling occurred on two or more welds simultaneously. These loads are presented in column 7, Table 2. Thereafter there was a redistribution of stress and the load could be increased approximately 20 per cent, at which load (column 8, Table 2), one or more of the welds would show a visible crack at the top end extending from the root of the weld outward (in many cases at an angle of approximately 30° with the end of the angle rather than directly across the throat section). From this point on small increases in load were accompanied by large increases in deformation, the weld slowly tearing with the increase in deformation. There usually occurred several points of yield when the head of the machine could not follow the deforming angle fast enough, but these seemed to have no significance. The final load, column 9, Table 2, is that load at which the test was stopped and is significant to the extent that the specimen refused to accept any further load without excessive deformation. Generally the gap between the plate and the heel of the angle was $^3/_8$ in. at the conclusion of the test. A typical specimen at the completion of the test is shown in Fig. 7.

(*c*) The deflections of the outstanding leg, as measured by the Ames dials, were plotted using total load as ordinates and observed deflections under the load point as abscissas. In all cases the resulting load-deflection curve was a straight line up to a definite yield point when the ratio of the applied load to the deflection decreased considerably.

The point at which the slope of the curve became 50 per cent greater than the initial slope was designated as the yield point. These yield-point loads averaged 83.3 per cent of those at which the whitewash scaled on the fillet of the angle.

(*d*) The observations of the strains in the top end of the welds by means of the tensometers were not entirely satisfactory since many instruments (14.5%) failed to function because of the congestion of apparatus at this location. There was some spread between the readings of the individual tensometers on the same specimen (71% of the readings were within 20% of the average), which gives some indication of the localized nature of the strains and suggests the possibility of locked-up stresses due to the welding. No correlation between these results and the method of welding seemed possible. It was noted that, as the load increased to the yield point, the portion of the load assumed by each weld, as measured by the tensometers, became more nearly equal. It was further noted that when the four tensometer readings were averaged and plotted as abscissas against the load as ordinates, see Fig. 8, the resultant curves were again straight lines up to yield point.

(*e*) The observations of the five tensometers on the lower edge of the vertical leg of the angle were plotted against the load per angle. Figure 9 shows a typical curve of the downward deflection of the ends of the seat angle under lever arms of 1.2, 2.0 and 3.0 in., and the center deflections under a lever arm of 1.2 in. The vertical intercepts may indicate certain friction loads. It is believed that the parabolic shape of the first portion of the curve is due to the action of these frictional forces which are gradually overcome as the load increases.

3. *Full Size Tests.—Series B.* Four tests were made under this series as follows:

B 444 Test No. 1 in which the beam was loaded at the center with a concentrated load. The yield point of the the beam was reached at 85,000 lb. total load, corresponding to a maximum unit stress of 31,300 lb. per sq. in. in the beam. Since no distress was evident at the seat angles and it was not desired to harm the loading beam, the load was released and quarter-point loading was substituted. This set-up is shown in Fig. 4.

B 444 Test No. 2 was the same set-up as Test No. 1 except that the loads were applied at the quarter points and the loading was increased until the welds failed.

B 643 was a similar test with quarter-point loading, using the same loading beam but replacing the stub columns and seat angles.

Specimen B 444B was made up with the beam ends bolted to the outstanding legs of the seat angle with $^7/_8$-in. diameter, fitted bolts, whereas in the previous specimens the beam was welded to the angle.

Ames dial observations of the downward deflection of the outstanding leg were plotted against the applied load. The resulting load-deflection curves are straight lines to a load approximately equal to the load at which the whitewash on the beam web at its junction with the lower flange scaled. Table 3 presents these loads: line 5, that which may be called the proportional limit as taken from the curves; and line 6, the load at which the whitewash on the beam scaled. For greater loads the deflection increased more rapidly than the load. It is necessary here to consider the relative stiffness of the beam and the angle. In these tests the beam was very stiff in relation to the angle. At zero load, the end of the beam had full bearing on the outstanding leg of the angle; the same condition probably held for low loads, and the reaction may be considered as uniformly distributed over the full interface. Upon the application of greater loads the slope of the outstanding leg of the angle became greater than that of the end of the beam. Thus the reaction became concentrated near the end of the beam. This increased the local compressive stress in the web at the end section, which soon reached the yield point, gradually permitting adjacent web material to carry portions of the load. The line of the reaction thus moved toward the toe of the angle. The increase in the effective lever arm accounts for the disproportionate deflections after the yielding of the web.

The tensometer measurements of the downward deflection of the angle obtained at the other column when plotted against the load showed curves similar to those of Fig. 9.

The deflections of the center of the beam checked the calculated deflections within one per cent, thus showing the negligible stiffening effect on the beam of the outstanding leg of the seat angle.

The Whittemore gage readings taken to show stresses in the lower flange of the loading beam and the slip, if any, between the seat angle and the loading beam, showed much greater strains than the common beam formula leads one to expect at these points. These readings are plotted against the load in Fig. 10 and an

Table 3—Results of Tests—Series B (Bare-Wire Welds)

		B 444 Test No. 1	B 444 Test No. 2	B 643	B 444B
(1)	Specimen No.				
(2)	Size of Angle, In.	4 × 4 × 1/2	4 × 4 × 1/2	6 × 4 × 1/2	4 × 4 × 1/2
(3)	Weld Data — Fillet Size, In.	1/2	1/2	3/8	1/2
(4)	Weld Data — Length, In.	8	8	12	8
(5)	Proportional Limit from Inspection of Curves, Lb.	27,750	45,000	22,560	53,000
(6)	Scaling of Web of Beam at Tension Flange, Lb.	30,000	40,000	19,500	67,400
(7)	Scaling on Fillet of Angle, Lb.	45,000	51,500	28,000	30,470
(8)	Scaling at Top End of Weld, Lb.	40,000	48,500	33,500	55,000
(9)	Crack in Top End of Weld, Lb.	....	54,500	59,000	65,250
(10)	Final Load, Lb.	45,000	60,000	62,500	67,400

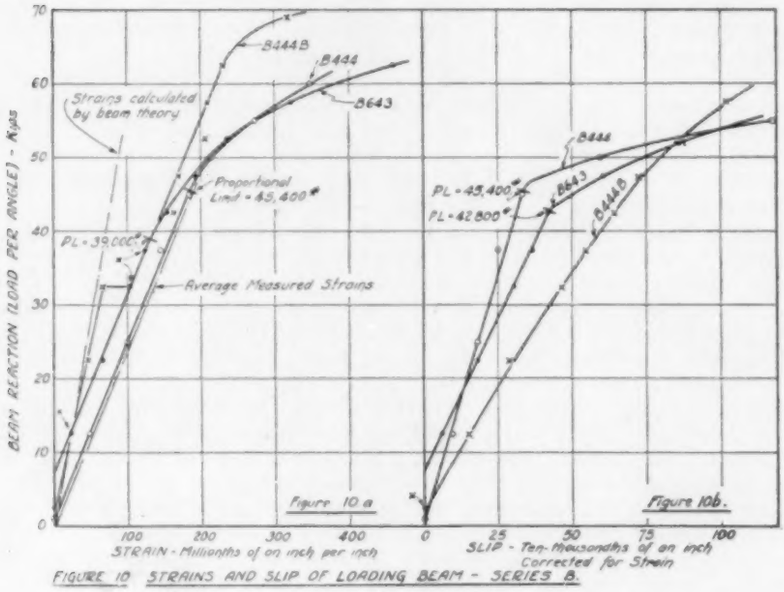


FIGURE 10 STRAINS AND SLIP OF LOADING BEAM - SERIES B.

explanation is given in the discussion to follow. The level bar indicated that the columns tilted outward due to the thrust from the lower flange of the beam. The tilting of the columns was proportional to the applied load and amounted to 0.0000645 radians per kip load per angle for B 444 Test No. 1, and to 0.000066 radians per kip load per angle for B 444 Test No. 2 and B 643.

The load at which the angle yielded is presented in line 7 of Table 3, the load at which scaling of the weld occurred in line 8, the load at cracking of the weld in line 9 and the final load at which yielding of the whole end connection became general in line 10.

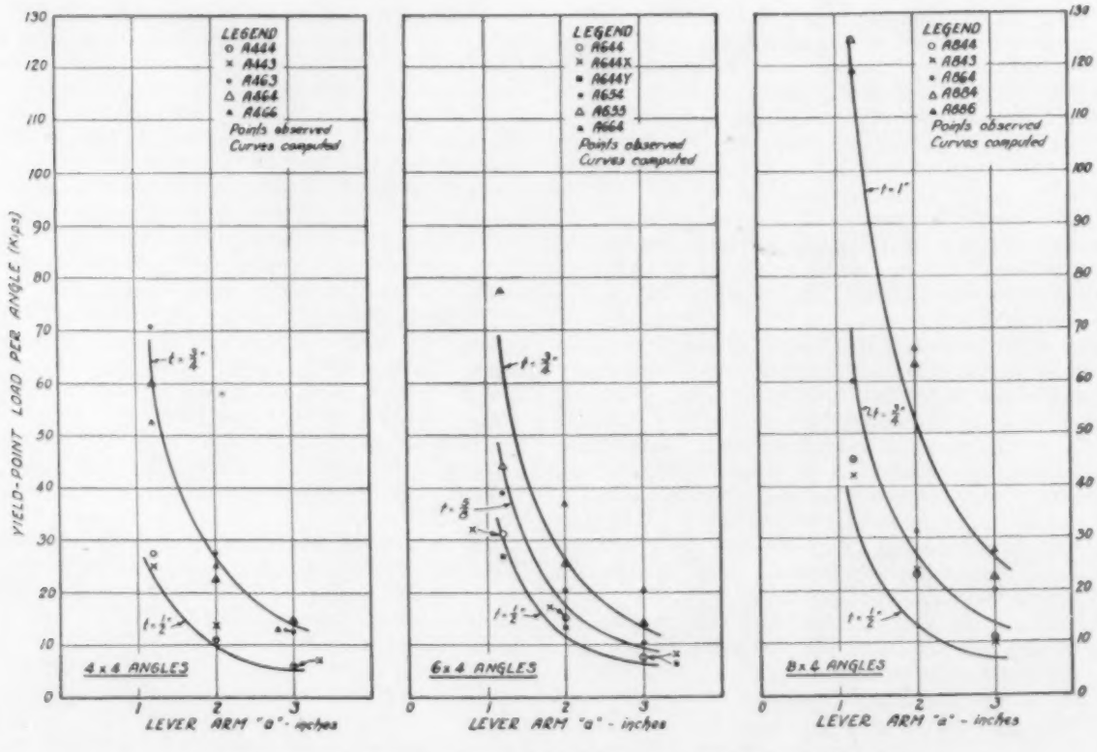


FIGURE 11 RELATION BETWEEN LEVER ARM AND STRENGTH OF ANGLES.

V. Discussion of Results

1. *Series A.*—The relation between the variables given in section III-2, and the capacity of the connection will be discussed in order.

(*a*) Figure 11 shows the relation between the lever arm and the yield-point strength of the angles, using the yield-point loads as defined in section IV-2*c*. The curves shown are those calculated by the method presented in section VI-*a*, and, except in some cases (notably Specimens A 664, A 843 and A 844), they agree very well with the observed data.

Figure 12 shows the effect of the lever arm on the strength of the weld, the ordinates being the values in column 7, Table 2. Here the product of the load times the lever arm tends to remain constant, on the assumption that the effective lever arm is the distance from the back of the angle to the center of the roller minus half the dimension of the weld fillet. The use of either the total distance from the back of angle to the center of roller or this distance minus half the thickness of the angle as the lever arm gives results almost equally satisfactory. However, from a study of the data of the deflection of the outstanding leg of the angle, and of the strength of the weld, the lever arm seems to decrease as the weld size increases; hence the first-mentioned value for the effective lever arm was chosen.

It is a matter of observation that the neutral axis of the weld was considerably above the midheight but it seemed impractical to determine the actual location. Its location apparently varied somewhat with the lever arm and with the load itself.

(*b*) A comparison of specimens A 644-1, A 644X-1 and A 644Y-1, all with lever arms of 1.2 in., but varying in that the load was applied through rollers centered on the outstanding leg of the angle over its full length, over 1 inch, and over 3-in. lengths respectively, shows negligible differences in the strength of the weld with this varying concentration of load. Neither the downward deflection of the outstanding leg nor the observed yield point of the angle was appreciably affected, but there was considerable local yielding immediately under the shorter rollers. From these tests we may assume that variations in the longitudinal distribution of the load, if symmetrically placed on the outstanding leg, introduce but small changes in the strength of the connection.

(*c*) Figure 13 shows the effect of the length of the vertical leg on the yield-point load of the angles. The observed yield-point loads were corrected for variation in the value of the yield-point stress of the material as given in Table 1. In general, the carrying capacity of the angle did not increase directly with the length of the vertical leg, and in some cases there was a decrease in the yield-point load for the longer vertical legs. The trend was not well marked and it seems that the length of the vertical leg had little, if any, effect on the yield-point load of the angle.

Figure 14 shows the effect of the length of the vertical leg on the load at which the weld scaled. Results from the $^1/_2$-in. angles with the $^3/_8$- and $^1/_2$-in. welds and $^3/_4$-in. angles with $^1/_2$-in. welds are available for comparison. In all cases the load at which the weld scaled increased noticeably with increase in the length of the vertical legs. It should be noted, however, that this increase in carrying capacity of the welds was not directly proportional to the increase in the length of the vertical leg.

(*d*) Figure 15 shows the relationship between the thickness of the angle and the load carried at its yield point. The observed data were plotted after correction was made for the variations in the yield-point stresses of the material. The loads calculated by the method given in the section on theoretical analysis are also presented. Again Specimens A 664, A 843 and A 844 fall beyond the calculated loads while the other values agree rather well. The curves show that the decrease in the radius of the fillet of the angle affects the carrying capacity of the angle. The 4 by 4-in. angles have a fillet radius of $^3/_8$ in. while the 6 by 4 in. and 8 by 4 in. have a fillet radius of $^1/_2$ in. The calculations show that the maximum unit stress in the angles having the $^1/_2$-in. fillet is only 88 per cent of that set up by the same load in an angle with a $^3/_8$-in. fillet. The test results substantiate this conclusion, giving a ratio of 89.8 per cent while the photoelastic tests[2] showed an average ratio of 84.5 per cent.

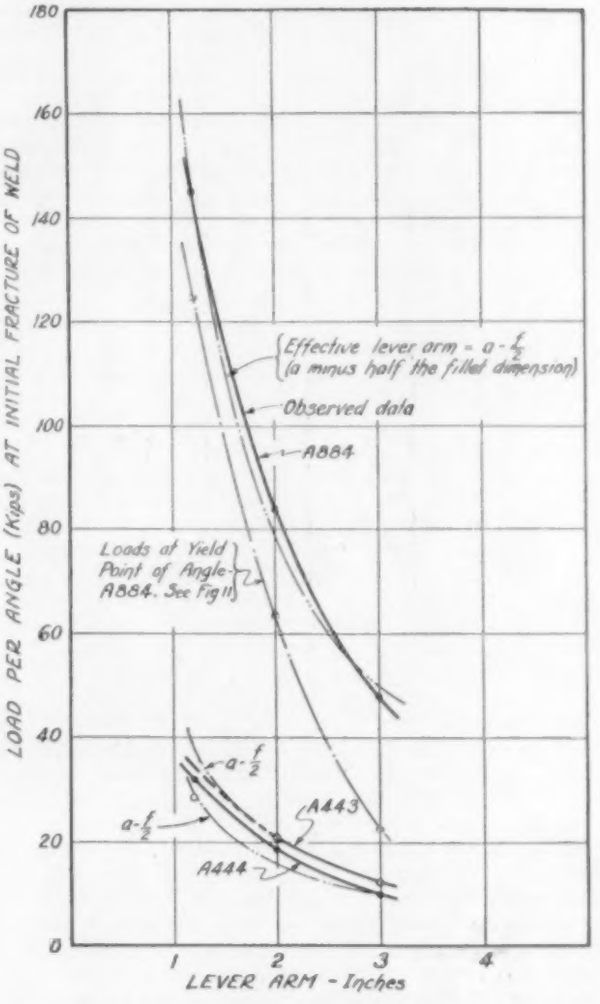


FIGURE 12. RELATION BETWEEN LEVER ARM AND STRENGTH OF WELD.

Figure 16 shows the relationship between the strength of the weld and the thickness of the angle. These curves indicate that the strength of the weld is dependent not only on its length, but to a far greater extent upon the thickness of the angle. These curves are of a higher order than second degree parabolas indicating that the strength of the weld increases slightly faster than the square of the thickness of the angle.

If these values are corrected for the variation in yield-point strength of the parent metal, the curve of the 8 by

[2] Inge Lyse and Douglas M. Stewart, "Photoelastic Study of Bending in Welded Seat Angle Connections," JOURNAL AMERICAN WELDING SOCIETY, Feb. 1935.

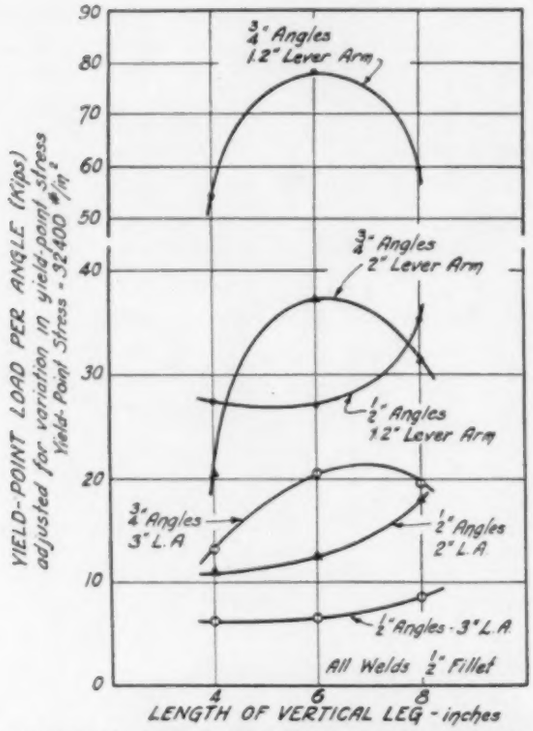


FIGURE 13. RELATION BETWEEN LENGTH OF VERTICAL LEG & STRENGTH OF ANGLES.

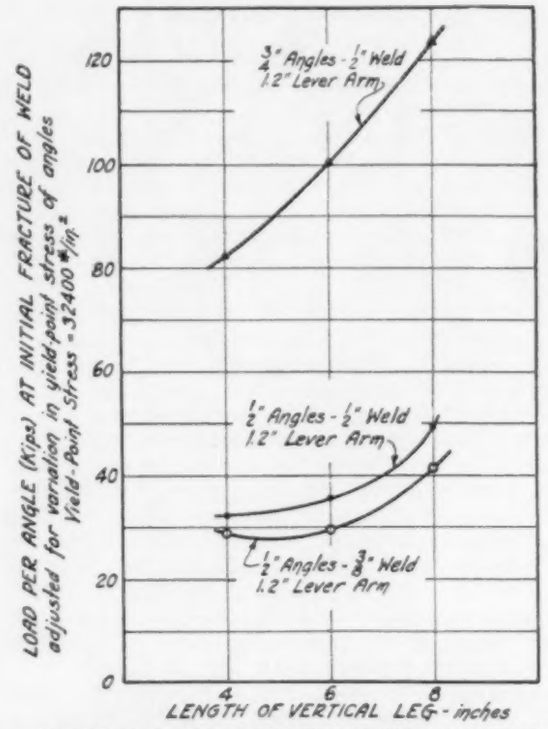

LOAD PER ANGLE (Kips) AT INITIAL FRACTURE OF WELD
adjusted for variation in yield-point stress of angles
Yield-Point Stress - 32400 #/in²
3/4" Angles - 1/2" Weld
1.2" Lever Arm
1/2" Angles - 1/2" Weld
1.2" Lever Arm
1/2" Angles - 3/8" Weld
1.2" Lever Arm
LENGTH OF VERTICAL LEG - inches

FIGURE 14. RELATION BETWEEN LENGTH OF VERTICAL LEG & STRENGTH OF WELD.

4-in. angles is a second degree parabola excepting the value of A 884-1, while those of the 4 by 4-in. and 6 by 4-in. angles correspond more nearly to higher degree parabolas, showing that the strength of the weld increased faster than the square of the thickness of the angle and was at the same time dependent on the yield-point strength of the parent metal. The value for the A 884-1 is low, most likely caused by the one-sided failure of this specimen.

Attention should be called to the effect of the thickness of the angle on the type of weld failure. The vertical leg of the angle will bend outward in the top part, thus causing a large amount of tension in the top end and subsequent fracture of the weld soon after the angle yields. However, a different kind of failure occurs when using a combination of heavy angles and light welds at the 1.2-in. lever arm. The angle will yield as before and the weld will fracture at the top end, but the additional load necessary to continue deflection of the angle is great enough to overstress the weld in shear, and the final failure will be one in shear throughout the full length of the weld. Specimens A 463-1, A 464-1, A 664-1 and A 884-1 failed in this way at shearing stresses in the weld of 14,030, 16,700, 15,270, 12,750 lb. per lin. in., respectively. Specimen A 466-1 is a border-line case, being on the point of failure in shear at a stress of 23,200 lb. per lin. in. It will be noted that in these cases the weld stress at final load, obtained by dividing the final load by the total length of weld, approached and, in some cases, exceeded the ultimate strength ordinarily assigned to such welds. Figure 17, a picture of A 884-1, shows a typical example of this type of failure.

(*e*) *Effect of Size of Weld.*—1. Specimens A 443 and A 444 may be compared under this heading. The ultimate load per inch of weld was 33 per cent greater for the $^1/_2$ in. than for the $^3/_8$-in. weld, which corresponds to the nominal increase of ultimate load with increased fillet size. The effect of size of weld on the load at which initial fracture occurred was less than on the ultimate load. At the 2.0-in. lever arm, the $^1/_2$-in. weld was only 8 per cent stronger than the $^3/_8$-in. weld; while at the 3.0-in. lever arm, the difference disappeared entirely.

2. Specimens A 463, A 464 and A 466 may likewise be compared. The specimen with the $^1/_2$-in. weld showed an increase in strength of 19 per cent (should be 33% theoretically) over that with the $^3/_8$-in. weld; the specimen with the $^3/_4$-in. weld showed an increase in strength of 39 per cent (should be 50%) over that with the $^1/_2$-in. weld. In each case the final loads were compared since the failures were of similar nature.

3. In comparing Specimens A 643 and A 644, the $^1/_2$-in. weld showed a superiority of only 19 per cent (should be 33%) over the $^3/_8$-in. weld with the 1.2-in. lever arm.

4. On the other hand, the $^5/_8$-in. weld showed a superiority of 33.3 per cent (should be 25%) over the $^1/_2$-in. weld (specimens A 654 and A 655).

5. A comparison of Specimens A 843 and A 844 showed a 19 per cent (should be 33%) increase in load at initial fracture of the $^1/_2$-in. weld over the specimens with the $^3/_8$-in. weld. For some unexplained reason both the $^3/_8$-in. and $^1/_2$-in. welds cracked at the same applied load, while the final load on the specimen with the $^1/_2$-in. weld was even less than that on the specimen with the $^3/_8$-in. weld.

6. Specimens A 884-1 and A 886-1 showed no marked difference at either initial fracture or ultimate strength, although A 886-1 should have been 50 per cent stronger than A 884-1. A 886-1 failed prematurely due to poor fusion at the top ends of the welds for a depth of approximately three-eighths of an inch.

Summing up the results of the tests concerning the effect of weld size, it seems safe to say that the weld size does affect the strength of the connection but not in direct proportion to the increase in size. The excess deformations which accompanied the yielding of the out-

standing leg of the angle apparently caused the weld to fracture prematurely at the top.

It is evident from the economic standpoint that the weld size should be kept as small as possible. Comparison of the $^1/_2$ in. with the $^3/_8$ in. welds shows that while the theoretical strength should increase 33 per cent, both material and labor increase about 78 per cent for the larger weld.

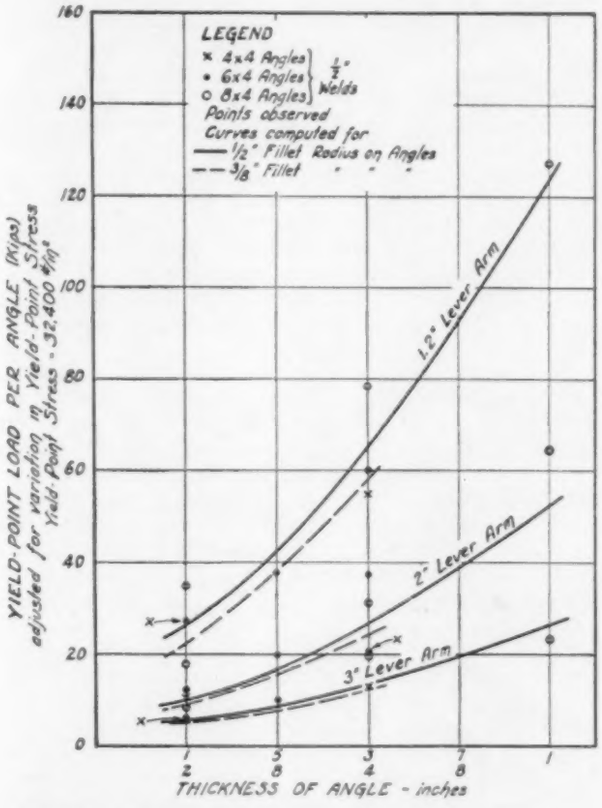


FIGURE 15. RELATION BETWEEN THICKNESS AND STRENGTH OF ANGLES.

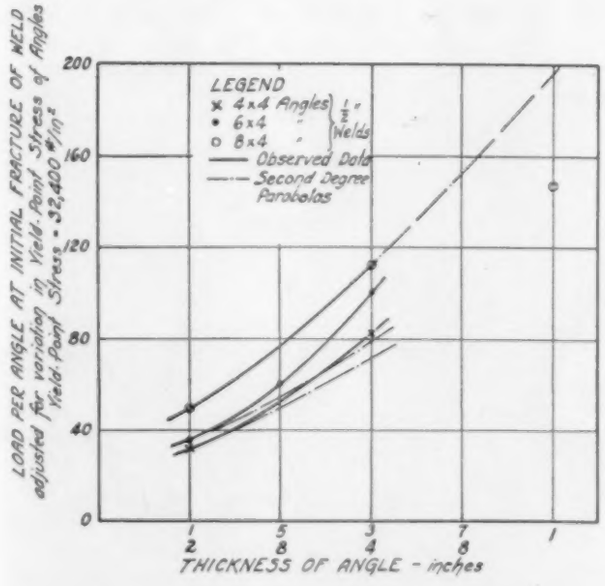


FIGURE 16. RELATION BETWEEN THICKNESS OF ANGLES AND STRENGTH OF WELD.

(*f*) *Effect of Type of Welding Rod.*—Specimens A 444C-1, A 644C-1 and A 644D-1 were welded with several commercial brands of heavily coated electrodes and may be compared with their companion specimens A 444-1 and A 644-1 which were welded with "bare wire." The qualification specimens indicated a gain of 23.5 per cent in the ultimate strength for the coated-wire specimens over the bare-wire specimens. A comparison of the seat angle specimens indicated that the deflections of the angle and its yield-point load were approximately the same regardless of the type of welding rod used. The results obtained from A 444C-1 must be corrected for the difference in yield-point strengths of the material before comparison can be made with the results obtained from A 444-1. The load at which the weld scaled was about 5 per cent greater for the coated-wire specimen than for those welded with bare wire. The load at which the welds actually cracked was approximately 29 per cent greater for the coated-wire specimens. This compares favorably with the increase in ultimate strength of the coated wire over the bare wire shown in the qualification tests mentioned above. The type of failure of the coated-wire specimens was also more advantageous to the connection. Evidently owing to the greater ductility of the metal, the readjustments in stress distribution after the yield point of the weld metal was reached were more gradual in the coated-wire specimens, and there occurred no sudden drop of the beam; the load slowly increasing until fracture occurred. The fracture always started at the root of the weld and proceeded across a section at an angle of about twenty degrees with the end of the outstanding leg of the angle (definitely less than the corresponding angle that occurred with the bare-wire welds). The fusion in all cases was good and the resulting weld metal very homogeneous. The welding time using coated wire was approximately two-thirds of that required for bare wire.

Summing up the results of the coated-wire tests it appeared that the use of coated wire increased the ultimate strength of the connection in about the same ratio as the strengths of the welds without greatly increasing the load at which scaling first occurred. However, the yield point of the outstanding leg of the angle was unaffected by the type of welding wire used. It was, therefore, the reserve strength of the connection which was increased by the use of coated wire. Other advantages were the more favorable type of failure, the better weld metal characteristics and the saving in welding time. On the other hand, welding with the fastest types of coated wire must be done in a horizontal position, which is satisfactory in shop work, but may be impractical in the field.

(*g*) *Auxiliary Tests.*—In addition to the regular schedule, a test was made incorporating certain features which seemed to lead to more economical design. This was A 444a in which the total length of welding was only 4 in., 2 in. at each end, starting from the heel of the angle. These welds failed at the top end in the usual manner and upon further addition of load continued to tear until the angles suddenly split off. Inspection of the break exhibited a typical tension fracture in the upper half of the weld, while the lower half showed the silky texture of shear failure. It is to be noted that the shorter length of weld used in this specimen did not decrease its carrying capacity in any respect, and significantly points out the inefficiency of the welding on the lower half of the vertical leg of the angle.

(*h*) *General Remarks.*—It is to be noted in Table 2 that the results obtained from Specimen A 443-1 were somewhat low as compared to those of later specimens. This was probably due to the outward deflection of the

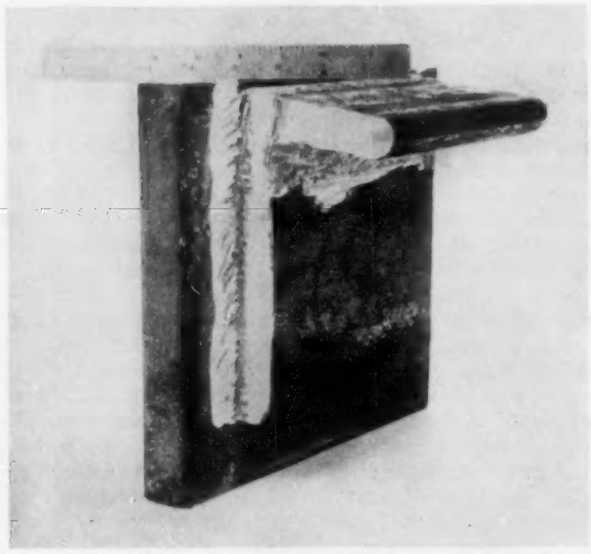


Fig. 17—Typical Example of Weld Failure in Shear—Specimen A 884-1

vertical legs of the loading rig allowing the lever arm of the load to increase and causing a lowered carrying capacity of the angle, as shown in columns 7, 8 and 9.

The high values observed for A 843-1 and A 844-1 were due primarily to the high yield-point strength of the parent metal. Because of the one-sided type of failure of A 844-1 its ultimate load (columns 8 and 9) was lower than that of A 843-1.

2. *Series B.*—In discussing the results of the few tests made in this series certain general phenomena will be pointed out. Consideration will first be given to the action of the beam end in transferring the load to the seat angle. Since the beam flange was quite heavy relative to the outstanding leg of the angle, the reaction was concentrated near the very end of the beam, causing a rapid increase in compressive stress at the junction of the flange and the web and subsequent yielding of the web at a low load. At the same time, the outstanding leg of the seat angle deflected downward under the action of this load, being restrained only to a slight degree by the fillet welds connecting the flange to the outstanding leg. The toe of the angle at the center pulled away from the bottom surface of the flange to such an extent that at 100,000 lb. total load it was possible to insert a feeler 0.040 in. thick between the flange and the toe of the angle for a distance of approximately $1^1/_4$ in. This threw considerable stress in the tack welds and slight cracks were noticeable in the near ends of them. As the web yielded near the end of the beam, it borrowed on adjacent web and flange material for assistance and the reaction tended to move outward, thus increasing the deflection of the outstanding leg considerably. The point at which this deflection ceased to be proportional to the applied load corresponded generally with the observed yielding of the beam web, while the yield point of the angle, as determined by a slope of the curve 50 per cent greater than the original slope, corresponded generally with the observed scaling of the whitewash on the angle fillet. Figure 18 shows a typical failure of one end of a full-sized connection.

Figure 10*a* shows the strains set up in the lower flange of the loading beam as determined by the Whittemore gage. The strains measured in this manner were greatly in excess of those which would be expected at the center of the gage length by the common beam theory. This may be explained by the yielding of the beam web referred to above, which had the same effect as a slit in the web of the beam, causing this end section to act independently of the main body of the beam and increasing the stress in the lower flange.

Figure 10*b* shows the relative motion between the flange and the outstanding leg of the angle. The end of the beam pulled away from the heel of the angle thus inducing considerable stress in the tack welds between the flange and the outstanding leg. The restraint offered by these welds may also account for the high values of the measured strains in the beam flange.

If B 444 is compared with A 444-1, its companion, we note the following: yielding of the angle in the Series B test occurred at 36,200 lb. (corrected for yield point of 40,260 lb. per sq. in.), as compared to approximately 30,000 lb. in the test of Series A at 1.2-in. lever arm. Evidently the resultant reaction of the beam acted closer to the heel of the angle than 1.2 in. From Fig. 11 we conclude that the carrying capacity increases rapidly as the lever arm decreases, hence this resultant reaction probably lies somewhere between 1.0 and 1.2 in. from the heel of the angle. Similar reasoning and the high yield point of the parent metal will account for the high strength of the welds.

The results from Specimens B 643 and A 643-1 may also be compared. Yielding of the angles occurred at a load of 28,000 lb. in Series B and at approximately 29,000 lb. at the 1.2-in. lever arm in Series A. Scaling of the whitewash on the top end of the welds first occurred at a load of 33,500 lb. in Series B corresponding to a like phenomenon on the companion specimen at 33,800 lb. in Series A. From the above comparisons it seems safe to assume that the position of the resultant reaction was quite close to 1.2 in. from the heel of the angle.

Specimen B 444 B may also be compared with A 444-1. Owing to the fact that the loading beam was used on previous tests, the lower flange for a distance of 3 in. from either end had an initial slope of approximately 0.042 in. per in., because of the yielding referred to previously. This initial slope caused the beam to rest on the toe of the angle. As the load was applied, the reaction moved toward the heel of the angle. The deflection curves of the outstanding leg indicated that the lever arm of the resultant reaction was between 1.2 and 2.0 in., and the load of 24,600 lb. (corrected) at which the angle scaled,

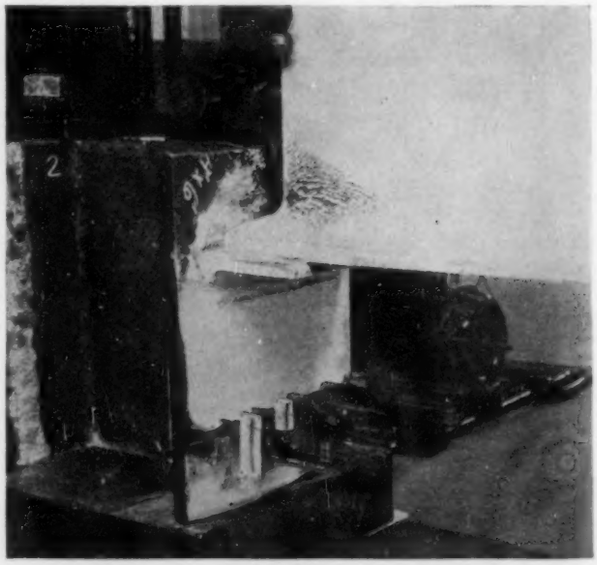


Fig. 18—Series B Specimen Showing Strain Lines and Typical Failure

is to be compared with 30,000 and 18,850 lb. for these respective lever arms of Specimen A 444. Scaling of the weld and final fracture occurred at only slightly greater loads than those of Specimen B 444. The influence of the prebending of the beam was especially noticeable in the more even distribution of load over the lower flange of the beam. At the load at which the web scaled, the stress in the web as computed by the method of section VII-1, assuming $1^7/_8$-in. bearing was 30,800 lb. per sq. in., which corresponds to the yield-point stress of 31,300 lb. per sq. in. for the web material of the beam.

Turning to Fig. 10*a*, the measured strains in the lower flange correspond closely to those calculated by the beam theory up to the load at which scaling of the angle was observed. Beyond this point the strains correspond closely to those of the previous tests in this series. Here again it seems that the reaction was rather uniformly distributed over the full contiguous surface of the beam and angle and induced no additional strains in the lower flange of the beam while the angle was taking the same slope as the end of the beam. However, when the angle yielded and the reaction moved closer to the end of the beam, local concentrations of stress increased the strains in the lower flange in the same ratio as in the previous tests.

The ends of this beam were bolted to the outstanding legs of the angle and the resulting greater flexibility is evident from Fig. 10*b*.

For these tests the end of the beam was set $^7/_8$ in. from the face of the column in order to get the worst condition probable in practice. This figure was calculated in the following manner. Specifications permit beams to be cut to the detailed length plus or minus $^3/_8$ in. Design practice allows for a clearance of $^1/_2$ in. between each end of the beam and the column. Any deviation from detailed length should be taken up symmetrically in laying out the beam; thus, a maximum gap of $^{11}/_{16}$ in. is possible. However, the layout is often made from one end which gives a possible gap of $^7/_8$ in. at the other end.

VI. Theoretical Analysis

(*a*) *The Angle.*—In the following theoretical analysis use has been made of the beam formula with its accompanying assumptions, many of which do not fully hold. However, the test results agreed very well with the values computed by the method presented herewith. In addition, test results were in most cases higher than those shown by theory and hence the theoretical loads and stresses given will be conservative.

The stress obtained by the use of the formula for beams with parallel faces may be transformed into tangential stress in the case of beams with non-parallel faces by dividing by the $\cos^2\theta$, where θ is the angle which the face makes with the perpendicular to the section under consideration,[3] since the maximum stress must be parallel to the surface and both the shear and the stress at right angles to the surface must be zero. However, when applied to the case at hand, this formula did not fit the observed data, probably due to the large inclination of the fillet of the angle to the assumed plane section.

In the following analysis use is made of a circular cross section which is normal to both surfaces of the angle and to the neutral axis, assuming it to lie in the center of the section. The assumption is made that the circular section before bending remains circular after bending (see Fig. 19). The ordinary beam formula is then used which gave the stress at the surface σ_t equal to:

[3] William Cain, "Stresses in Wedge-Shaped Reinforced Concrete Beams," *American Society of Civil Engineers, Transactions*, Vol. 77, p. 745 (1914).

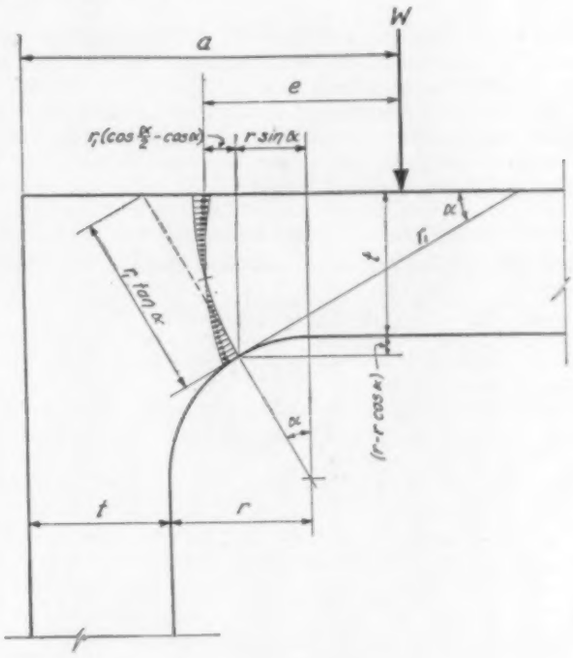


FIGURE 19. SECTION USED IN THEORETICAL ANALYSIS

$$\sigma_t = \frac{6We}{bd^2} \tag{1}$$

where W = the total load per angle
e = the effective lever arm of the load
b = the length of angle
d = the length of the circular section considered

From Fig. 19, e and d may be evaluated:

$$e = a - t - r + r\sin\alpha + r_1\left(\cos\frac{\alpha}{2} - \cos\alpha\right) \tag{a}$$

$$d = r_1\cdot\alpha = \left(\frac{t + r - r\cos\alpha}{\sin\alpha}\right)\alpha \tag{b}$$

Substitution of (*a*) and (*b*) in equation (1) gives:

$$\sigma_t = \frac{6W}{b}\,\frac{\mathrm{A} + (t+r-r\cos\alpha)(\cos\frac{\alpha}{2}-\cos\alpha)\alpha\sin\alpha}{[(t+r-r\cos\alpha)\alpha]^2} \tag{2}$$

$$\mathrm{A} = (a-t-r+r\sin\alpha)\sin^2\alpha$$

There is also a direct stress due to the inclination of the section assumed, varying from zero at the horizontal face to a maximum at the fillet of the angle (the point of maximum inclination). This stress at the fillet may be approximated by considering the component of the load, $W\sin\alpha$, distributed over the plane tangent to the cross section at this point. The area of this plane is $br_1\tan\alpha$. Then σ_c, the compressive stress at the face of the fillet, equals:

$$\sigma_c = \frac{W\cos\alpha}{br_1} = \frac{W\sin\alpha\cos\alpha}{b(t+r-r\cos\alpha)} \tag{3}$$

The total stress is:

$$\sigma = \sigma_t + \sigma_c \tag{4}$$

It will be noted that σ is dependent upon the angle α for its maximum and we should therefore obtain a value

for α which makes σ a maximum. Obtaining the maximum by calculus is so arduous and the resulting expression so cumbersome, that a graphical method furnishes the most convenient method of attack and yields values within 2 per cent of the maximum by using values of α no closer than every five degrees. Table 4 gives these results for the angles tested.

Table 4—Computed Values for Maximum Stress in Seat Angles

Thickness of Angle	Radius of Fillet of Angle	Value of α (Degrees) Giving Maximum Stress, Lever Arms			Value of Stress Factor K, Lever Arms		
		1.2	2.0	3.0	1.2	2.0	3.0
In.	In.						
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1/2	3/8	33.2	15	0	11.720	28.284	50.500
1/2	1/2	30	15	0	10.096	25.839	48.000
5/8	1/2	45	15	0	6.037	15.255	28.800
3/4	3/8	45	15	15	4.475	10.705	20.595
3/4	1/2	45	30	15	4.001	9.722	19.350
1	1/2	60	30	15	2.096	4.941	9.833

Maximum compressive stress on fillet of angle is given by:

$$\sigma = \frac{WK}{b}$$

where W = the end reaction per angle in pounds
K = the stress factor
b = the length of seat angle in inches

Loads per angle calculated from these results and the yield-point stresses given in Table 1 are plotted on Figs. 11 and 15, and their general agreement with the test data will be noted. The calculated values average about 10 per cent less than those actually obtained by observation from the load-deflection curves.

(*b*) Consideration of the weld stresses showed that they cannot be solved by the use of the ordinary theories of flexure when the weld is used in this position. The failure of the weld is brought about as a secondary effect caused by excessive deflection of the angle as it is stressed beyond the yield point.

VII. Recommendations for Design

On the basis of the results of this investigation, the following methods for designing seat angle connections are recommended.

1. *Design of Beam and Location of Resultant Action.*—The beam which is supported by the seat angles is subjected to high compressive stresses in the web immediately above the point of support. These compressive stresses will cause failure of the web in "crippling"[4] if they become very large. The web should therefore be designed against crippling failure. Tests[5] have indicated that the crippling will take place when the compressive stress in the web exceeds the yield-point strength of the material. The maximum stress permitted should therefore be computed by the formula:

$$\sigma_c = \frac{W}{(m + N)\,t} \tag{5}$$

where σ_c = permitted stress in compression
W = reaction of the beam on the seat angle
m = length of bearing on the seat angle
N = thickness of the flange including the fillets of the beam
t = thickness of the web of the beam

[4] "Crippling" is defined as the local failure of the web produced by excessive compressive stresses under a concentrated load.

[5] Inge Lyse and H. J. Godfrey, Discussion, "Investigation of Web Buckling in Steel Beams," *Proceedings, American Society of Civil Engineers*, Nov. 1934, p. 1354.

Since it will generally be the case that the seat angle will be more flexible than the flange of the beam, the reaction will tend to be concentrated near the end of the beam, and it will, therefore, reach the yield point first. The length of bearing "m" under these conditions will be zero and the necessary dimensions of the beam become:

$$Nt = \frac{W}{\sigma_{yp}} \tag{6}$$

where σ_{yp} is the compressive yield-point stress of the web material of the beam.

Local yielding of the web will cause redistribution of stress with a consequent higher carrying capacity. It seems safe, therefore, to permit web stresses very nearly equal to the yield-point stress when zero bearing length is assumed.

2. *Design of Angle.*—The outstanding leg of the angle must be designed to resist the flexural stresses developed due to the eccentricity of the reaction. The stresses set up in the angle will reach a maximum in compression on the fillet surface of the angle. The location of the point of maximum stress may be determined by the use of Table 4, where α is the angle between a vertical through the junction of the fillet with the outstanding leg and the plane of maximum stress.

The value of the stress factor "K" is given and the maximum compressive stress in the angle may be obtained from the formula:

$$\sigma = \frac{WK}{b} \tag{7}$$

where b is the length of the seat angle in inches.

3. *Design of Weld.*—In all of the tests included in this investigation, the yielding of the angle at the fillet was the first cause of excessive deformations. Consequently, the welds were all sufficiently strong to develop the full yield-point value of the angle. The yielding of the angle introduced secondary stresses into the weld which fractured from the top downward. This failure was very gradual with ample warning of impending danger. Where shear failure in the weld occurred, it followed the initial fracture of the weld in tension suddenly and with little warning. If, then, we prevent failure of the weld in shear, the strength of the connection will be dictated by the yield-point strength of the angle. Since a shear failure in the weld is a sudden break, with little or no warning, the factor of safety against shearing should be greater than against flexure.

The ultimate strengths these seat-angle welds developed in shear were found to correspond well with the ultimate strengths of the qualification welds. It is, therefore, recommended that the weld be designed for a shearing stress in conformity with the A. W. S. Code for Fusion Welding and Gas Cutting in Building Construction—Code 1, Part A, when the unit shearing stress, τ, is computed by the general formula:

$$\tau = \frac{W}{l} \tag{8}$$

where l is the total length of weld subjected to longitudinal shear.

VIII. Summary

Based upon the observed behavior of the specimens tested, the following general summary is presented:

1. The strength of a seat angle connection with welds at the ends of the vertical leg of the angles varies roughly as the square of the thickness of the angle, inversely as the effective lever arm of the resultant reaction, and is

influenced by the length of the vertical leg of the angle, and by the size of the weld.

2. Vertical shear has only a slight effect on the strength of the weld unless the angle is thick enough so that the bending deflection of the vertical leg is reduced to a minimum, in which case the vertical shear is a criterion. However, even in this case the tops of the welds were found to be most highly stressed and fractured first.

3. The centers of rotation for the calculation of the resistance of the weld were not located in these tests, but it is evident that they were not at the midheight of the weld.

4. Concentration of load longitudinally over varying lengths of the outstanding leg has no effect on the strength of the connection. A local yielding occurs directly under the point of application of the load.

5. The outstanding leg acts as a cantilever beam so long as the load is applied near the toe. As the load moves in toward the heel of the angle, the weakest section is somewhere across the fillet of the angle. This section can best be analyzed by studying the stress distribution on cross sections perpendicular to both faces of the outstanding leg.

6. Increase in size of weld increases the strength of the connection but not in proportion to the increase in weld size; furthermore, the added strength of the connection is far less in proportion to the increase in welding costs. Economically it would be desirable to keep the weld as small as possible.

7. The length of weld does not increase markedly the strength of the connection. It is probable that the weld needs be only slightly longer than is necessary to prevent shear failure, figured simply as the total load divided by length of weld. It appears evident that the bending moments set up give rise to no appreciable stresses in the lower portion of the welds.

8. An increase in the radius of the fillet of the angle decreases the stresses at the fillet to a marked degree. This is shown not only by the test data but also in the theoretical analysis and by the photoelastic studies.

9. The failure of the welded seat angle connection is gradual, except when the lever arm is so small that shear and not bending predominates. The weld gradually tears at the top allowing the angle to bend outward and downward.

10. The principal lever arm, i.e., the distance between the column face and the load for Series A was 1.2 in., which was estimated to be a proper value from considerations of the maximum possible gap between the beam and the column face and the probable position of the resultant reaction. This assumed value for the lever arm was rather closely substantiated in the tests of Series B.

11. Coated-wire welds were found to be effective in increasing the ultimate strength of the connection in approximately the same ratio that the ultimate tensile strength of the coated and "bare" wire bear to each other. However, the type of wire had no effect upon the yield-point load of the angle or on the first cracking of the weld.

12. On the basis of the observations and the simplified theoretical analysis made, it is recommended that seat angle connections with vertical fillet welds on the ends of the angles be designed first with respect to the strength of the angle itself and secondly with respect to the strenght of the weld in vertical shear.

A Photoelastic Study of Bending in Welded Seat Angle Connections*

By INGE LYSE and DOUGLAS M. STEWART†

Introduction

A PHOTOELASTIC investigation of the properties of welded seat angle connections was undertaken at the Fritz Engineering Laboratory of Lehigh University in conjunction with actual seat angle tests being carried on in cooperation with the Structural Steel Committee of the American Bureau of Welding. The investigation was limited by the nature of the apparatus to two-dimensional problems under plane loading, and consequently this study is confined to the lateral bending effect of the angles themselves. Furthermore, ideal welding conditions must be assumed and perfect continuity of welding material and parent metal. Since we note that, where sufficient weld metal is present to prevent a shear failure, the first symptoms of failure in actual seat angle tests are always a disproportionate increase in deflection of the outstanding leg, followed by chipping of scale or whitewash on the fillet of the angle, this bending effect is of prime importance as regards failure of the connection. Consequently, a correlation could be made between the results of the photoelastic tests and the data on the first signs of bending failure in actual tests, and the results of this are shown later in this report. In addition, a photoelastic model will show the distribution of stress in the angles at various loads and will permit the study of other factors which might affect the strength; in this case, the effect of increasing the size of the fillet in the angles as rolled was investigated as being of importance in causing bending rigidity.

Test Specimens

Three models were made and tested, these being half-scale sections of a pair of 4 x 4 x $^1/_2$ in., 6 x 4 x $^5/_8$ in. and 8 x 4 x 1-in. seat angles mounted on $1^1/_4$-in. thick plates exactly as in the actual welded steel specimens. These models were accurately machined from sheets of $^1/_4$-in. thick transparent bakelite and carefully polished and annealed to remove initial stresses. At the same time a calibration beam was cut from the same sheet of bakelite as each model, and subjected to the same conditions of annealing and storing. The models were then loaded by means of dead weights through rollers placed at the desired distance from the back of the angles, in a manner identical with the tests on the full-sized steel specimens. The two larger of these models were made with a 1-in. fillet on the angles, which was then cut down successively to $^3/_4$ in. and $^1/_2$ in., the latter being the standard size rolled.

Photoelastic Method of Analysis

It is possible by passing plane polarized light through such a transparent model, to obtain a series of dark lines on an image of the model from which the directions of the two principal stresses at any point, that is, the stress trajectories, may be determined. Furthermore, each fringe as shown when the model is subjected to circularly polarized light, represents a definite value of the difference of the two principal stresses (P-Q), at that point. Since the maximum shear is likewise proportional to (P-Q), these fringes are also lines of constant maximum shear. At the free boundaries of a model, where the stresses have in general their critical values, one of the principal stresses vanishes, and thus the fringe order is a direct measure of the fiber stress along the boundaries. This latter fact was made use of in this investigation and from the calibration beam under uniform bending moment, the value of the stress difference corresponding to the fringe values of each model was determined. From the values of the extreme fiber stress in the outstanding leg of the angles, moment curves were then plotted, and a first integration of these gave the slope at any point, while a second integration gave the deflection curve of the outstanding leg.

Variables Studied

The variables studied were as follows:

1. With the load at 2 in. from the back of angle, the load was varied.
2. With the load constant the lever arm was varied, the points selected being 1.2 in., 2.0 in., 2.5 in. and 3.0 in. from the back of angle.
3. From these results a comparison was made of the three fillet sizes, all other variables remaining constant.
4. The effect of the length of the vertical leg was studied by cutting down the 8 x 4 x 1-in. model in successive steps.
5. The effect of the size of the angle on the stresses produced was determined from the preceding results.

* Paper presented at Fall Meeting, A. W. S., October 1–5, 1934, New York. Contribution to the Structural Steel Welding Committee, A. B. W.

† Research Associate Professor of Engineering Materials and Research Fellow in Civil Engineering, respectively, Lehigh University, Bethlehem, Pennsylvania.

Fig. 1—Variation in Maximum Stress with Load

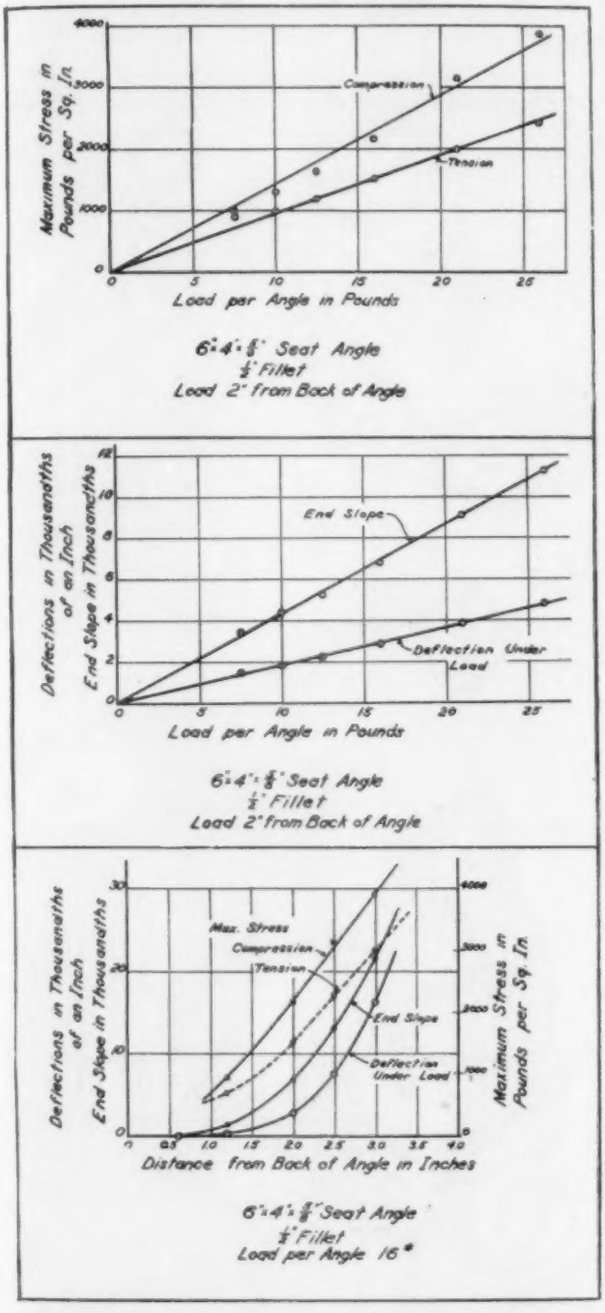


Fig. 2 (Center)—Variation in End Slope and Deflection under the Load with Load

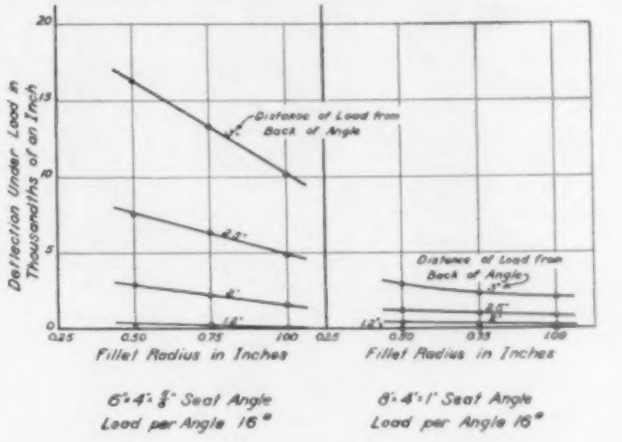
Fig. 3—Variation in Stress, Slope and Deflection under Load with Distance from Back of Angle

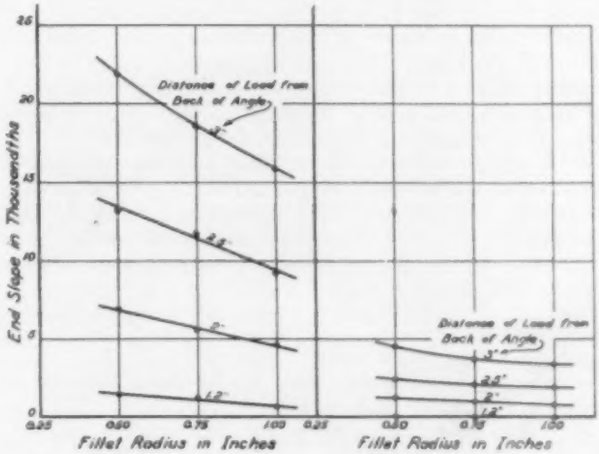
Discussion of Variables

Figure 1 shows the effect of the variation of load upon the maximum stress on both the tension and compression sides of the angle. As is to be expected, the relation is linear, the stress increasing directly with the load, and the compressive values exceed the tensile ones, indicating that the compressive stress at the fillet limits the strength of the angle.

In Fig. 2 is shown the variation in end slope and deflection under the load with varying loads and a constant lever arm. In this case the values lie more closely on the

Fig. 4—Deflection under the Load for Two Sizes of Angle with Variable Fillet Size


Deflection Under Load in Thousandths of an Inch
Distance of Load from Back of Angle
Fillet Radius in Inches
6"×4"×⅝" Seat Angle
Load per Angle 16"
Distance of Load from Back of Angle
Fillet Radius in Inches
8"×4"×1" Seat Angle
Load per Angle 16"


End Slope in Thousandths
Distance of Load from Back of Angle
Fillet Radius in Inches
6"×4"×⅝" Seat Angle
Load per Angle 16"
Distance of Load from Back of Angle
Fillet Radius in Inches
8"×4"×1" Seat Angle
Load per Angle 16"

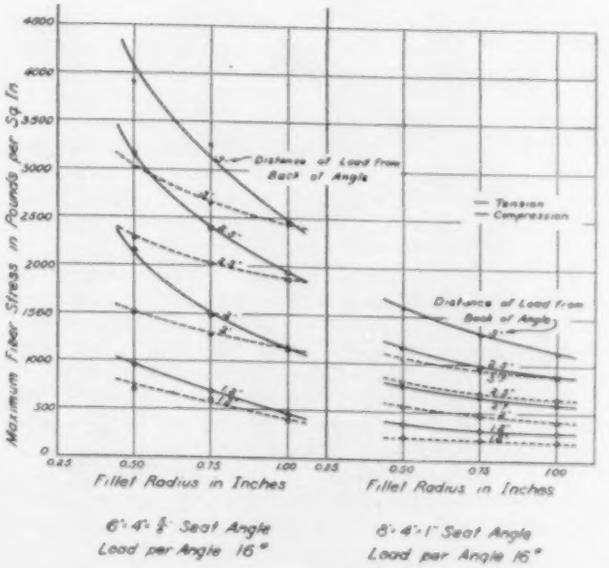

Maximum Fiber Stress in Pounds per Sq. In.
Distance of Load from Back of Angle
Tension
Compression
Fillet Radius in Inches
6"×4"×⅝" Seat Angle
Load per Angle 16"
Distance of Load from Back of Angle
Fillet Radius in Inches
8"×4"×1" Seat Angle
Load per Angle 16"

Fig. 5 (Center)—End Slope for Two Sizes of Angle with Variable Fillet Size

Fig. 6—Maximum Fiber Stress for Two Sizes of Angle with Variable Fillet Size

theoretical straight lines, since the process of integration by which they were obtained tends to iron out any irregularities in the data.

The constant load of 16 lb. per angle was then applied to each of the four lever arms, and Fig. 3 shows a typical set of results for the 6 x 4 x $^5/_8$-in. model with $^1/_2$-in. fillet. The maximum stress, both in tension and compression, is seen to vary linearly down to a point where the influence of the fillet is felt. The curve for the end slope is a parabola, while that for the deflection under the load is a cubic parabola, both modified at low values by the restraint caused by the fillet.

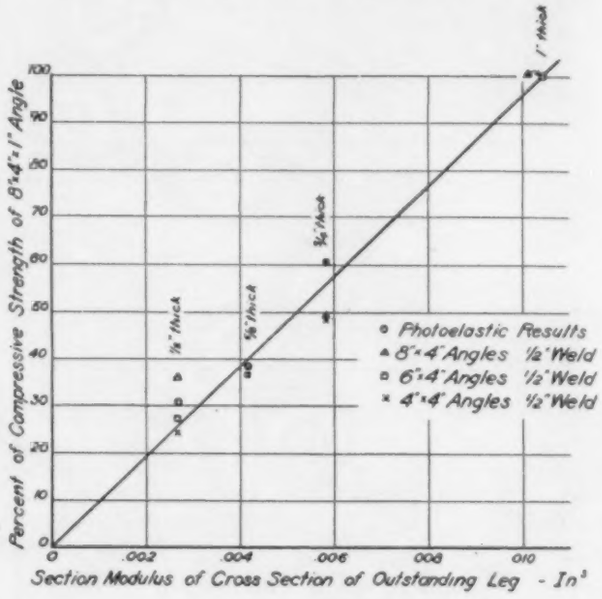
The quantitative effect of the size of the fillet in the angle as rolled is shown in Figs. 4, 5 and 6 for the three sizes tested. The first two figures showing the deflection under the load and the end slope at each of the four lever arms, indicate clearly the added rigidity caused by the larger fillets, and give as well a comparison of the stiffness of a 6 x 4 x $^5/_8$-in. and an 8 x 4 x 1-in. angle. Figure 6 shows the variation in maximum stress, both in tension and compression, as the fillet size is increased; it shows plainly that the less rigid angle is strengthened more by the addition of a larger fillet than is the stiffer angle. The amount of this stiffening has been summarized in Table 1, in which the maximum stress is expressed as a percentage of the maximum stress with a standard $^1/_2$-in. fillet. In addition, the percentage increase in weight of the standard angle caused by the increase in size of the fillet, has been tabulated. Since the compressive stresses limit the strength of the angle in every case tested, it is these values that are of the greatest significance, and the reduction of stress caused by the addition of only a very small amount of material is remarkable.

Table 1—Maximum Stress Expressed as a Per Cent of the Stress with $^1/_2$-In. Fillet

	Distance from Back of Angle	$^3/_4$-In. Fillet	1-In. Fillet
Load per Angle 16 Lb. 6 x 4 x $^5/_8$-In. Seat Angle			
Compression	3.0"	84.7	63.0
	2.5"	75.8	61.5
	2.0"	69.0	52.1
	1.2"	71.3	47.0
	Average	75.2	55.9
Tension	3.0"	89.3	80.5
	2.5"	88.5	81.5
	2.0"	84.5	77.5
	1.2"	90.5	55.8
	Average	88.2	73.8
Per Cent Increase in Weight of Section		1.2	2.7
8 x 4 x 1-In. Seat Angle			
Compression	3.0"	83.8	71.0
	2.5"	84.3	75.0
	2.0"	87.1	76.8
	1.2"	84.1	78.6
	Average	84.8	75.3
Tension	3.0"	88.9	83.0
	2.5"	86.3	79.1
	2.0"	85.0	75.0
	1.2"	92.8	88.5
	Average	88.2	81.4
Per Cent Increase in Weight of Section		0.6	1.5

The vertical legs of the 8 x 4 x 1-in. model, with a $^1/_2$-in. fillet, were cut down by $^1/_2$-in. steps, corresponding to 1 in. on the full-sized specimen, until they were $1^1/_2$ in. long and then by $^1/_4$-in. steps until 1 in. long. Photo-

Fig. 7—Curve Showing Relative Strength in Bending of Different Sizes of Seat Angles



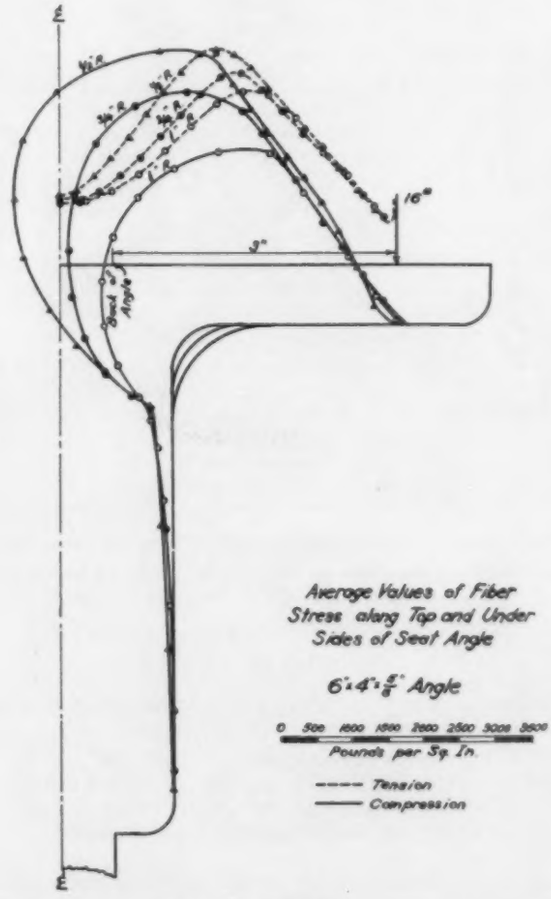
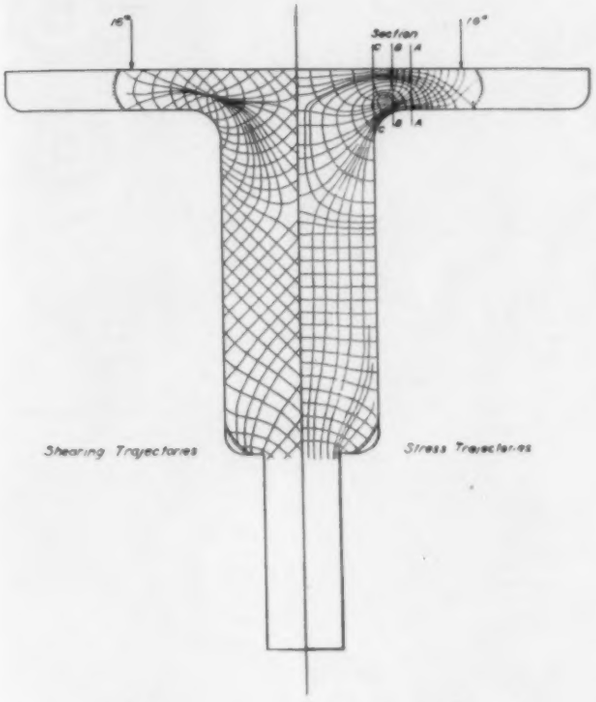


Fig. 8—Average Values of Fiber Stress along Top and Under Sides of Seat Angle

Fig. 9—Stress and Shearing Trajectories, 6 x 4 1/2-In. Angle



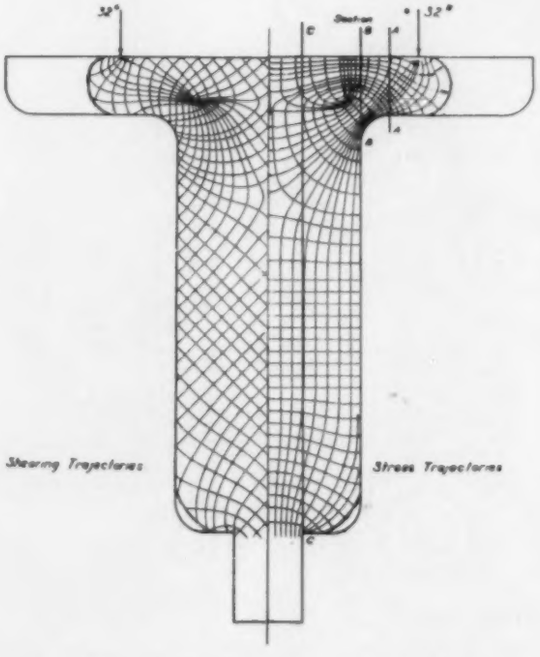


Fig. 10—Stress and Shearing Trajectories, 8 x 4 x 1-In. Angle

graphs taken of the fringes around the base of the angle show no increase in the tensile or compressive stresses until a length of $1^1/_2$ in. was obtained, corresponding to a 3-in. vertical leg below which the compressive stresses were slightly increased and redistributed. This is lower than used on any seat angles in practice, since considerable length of weld is needed to provide against shear failure, a factor which is not apparent from photoelastic results.

The relative strength of the three sizes of angles tested is shown in Fig. 7. Each angle has the standard $^1/_2$-in. fillet and the strength, or load required to produce the yield-point stress in each angle, has been plotted as a per cent of the strength of the 8 x 4 x 1-in. angle *vs.* the section modulus of a cross section of the outstanding leg of the angle. The points group themselves along a straight line, values for the 4 x 4 x $^1/_2$-in. angle being more in error because of difficulties in observing the large number of fringes present. Each point is the average for the four lever arms used. In addition, there is shown on this figure the relative strengths of actual full-sized welded steel specimens, these values being the loads at which the load-deflection curves for the outstanding legs had a slope 50% greater than the initial slope. Each point here is the average for the three lever arms used in the tests. A similar plot based on the yield point as determined by chipping of the whitewash on the fillet of the angle, shows a wider spread in values, due to the inaccuracy of such observations. This figure shows a fairly good correlation between photoelastic tests and the actual welded specimens and indicates that the section modulus of a cross section of the outstanding leg should dictate the selection of the thickness of a seat angle.

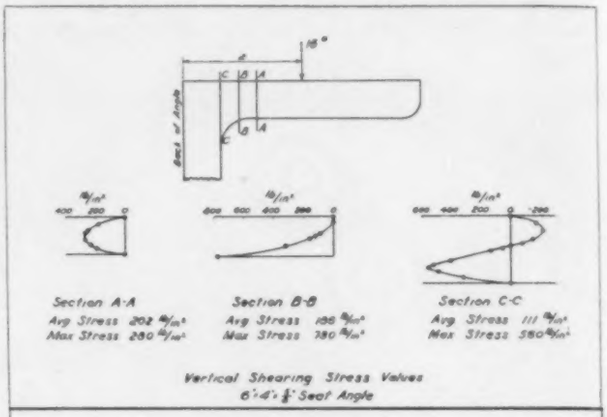
Stress Distribution

The distribution of stress in the extreme fibers along the boundary of the 6 x 4 x $^5/_8$-in. model is shown in Fig. 8 for the three different fillet sizes. This figure shows the load at 3 in. from the back of angle, the other lever arms showing identical effects. On the tension side, we may note that all the curves practically coincide outside of the fillet. Also they reach a maximum value directly above the point where the fillet commences, and this maximum value increases as the fillet size decreases; the effect of a local concentration of stress under the load point is likewise shown. On the compression side, ordinates around the fillet have been plotted radially. Again we note that the curves coincide beyond the fillet and that they reach zero values under the load. The maximum compressive stress occurs on the fillet at an angle of roughly 20–30° with the vertical, and the values increase with decrease in fillet size. It might be noted that chipping of the whitewash in full-sized tests, where shear failure does not occur, commences at this point on the fillet as nearly as can be observed. Finally, in the compressive portion of the specimen, the extreme fiber stress falls off rapidly and the lower tip of the angle takes no stress at all.

The directions of the two principal stresses have been determined by means of plane polarized light for the 6 x 4 x $^5/_8$-in. and the 8 x 4 x 1-in. models and are shown on the right halves of Figs. 9 and 10. These stress trajectories consist of two sets of mutually perpendicular lines, and at all free boundaries one set of lines is normal to the boundary. It is seen that the fibers are in almost pure tension just above the fillet and that pure compression exists at the fillet and in the main body of the model. The portions of the outstanding leg outside the load point and the lower tip of the vertical leg are under zero stress. On the left side of these figures are shown the directions of the maximum shearing stresses, or shearing trajectories, which are two sets of mutually perpendicular lines inclined at 45° to the stress trajectories. A singular point just over the fillet, shown in these two figures, has been found to be a point of zero stress, which may be said to correspond to the neutral axis. A similar study was made of each of the three fillet sizes, to determine whether this variable affected the stress distribution greatly. Slight variations were noted, but the distribution of stress was not markedly altered.

The vertical shearing stress was then analyzed by use of Mohr's Stress Circle along sections A, B and C as shown on Fig. 9 for the 6 x 4 x $^{5}/_{8}$-in. angle and the results are shown in Fig. 11. On section A we have the usual parabolic distribution of the vertical shear. At B the stress trajectories are horizontal and vertical for a short distance down from the top; hence, there is no vertical shear for a short distance. Also, since the lower edge of the section is inclined, the vertical shear has a value at this point. At C quite a different form of distribution is observed, an explanation of which may be seen by referring to Fig. 9. At C, down to a certain point, the lines of stress (in tension) are pulling up on the right side of the section instead of down as at A; in other words, the sign of the shear is reversed. Below this point the compressive forces are pushing down as at A, and the sign of the vertical shear is again positive. The worst section is at B, which is the transition point between diagrams of types A and C. Figure 12 shows the distribution of vertical shear on sections A, B and C of Fig. 10. In this case, the transition section lies between B and C, and we note again the reversal in sign of the shear on section C. Values of the average vertical shearing stress and also the maximum values are shown on these figures. The area under these curves, representing the internal shear, has been found to check the external shear within 10% in each case.

Fig. 11—Vertical Shearing Stress Distribution, 6 x 4 x $^{5}/_{8}$-In. Angle



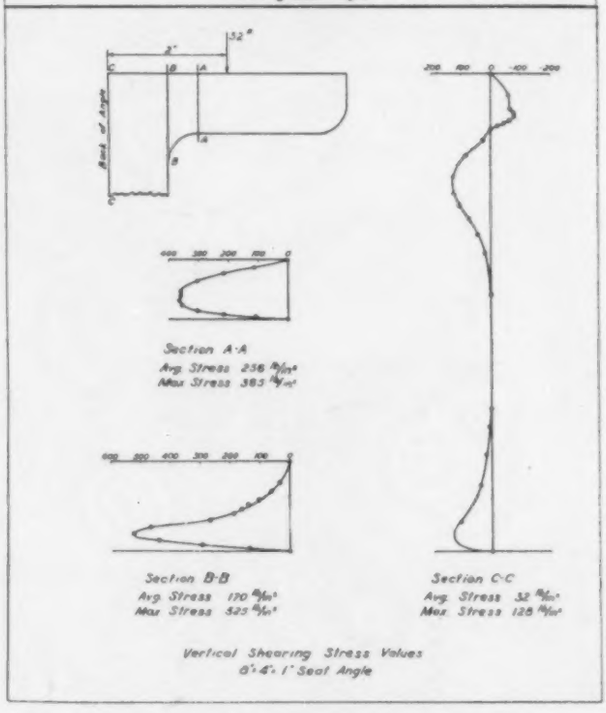


Fig. 12—Vertical Shearing Stress Distribution, 8 x 4 x 1-In. Angle

Conclusions

From the above results the following conclusions have been drawn with respect to the bending of seat angles below their elastic limits:

1. Provided sufficient metal is available in the fillet welds to prevent shearing failure, the limiting condition for permanent set in ordinary welded seat angle connections is determined by the bending strength of the angles.
2. The maximum compressive stress at the fillet of the angle is approximately $1^{1}/_{2}$ times the maximum tensile stress along the top side of the angle; accordingly, the strength of the angle in bending is determined by the compressive stress existing in the fillet of the angle.
3. The maximum stress, end slope and deflection for a constant lever arm, vary linearly with the load.
4. For a given load, the maximum stress varies linearly with the lever arm of the load, and the end slope and deflection under the load vary as second and third order parabolas, respectively, except near the fillet where these curves are all modified somewhat due to local concentrations of stress.
5. The addition of a very small percentage of material in the form of a larger fillet in the angles gives marked reductions in both tensile and compressive stresses, the effect being more marked on the weaker angle sections.
6. The length of the vertical leg has little or no effect on the stresses in the angle above a length equal to that of the outstanding leg; sufficient length must be provided, however, to prevent failure by shearing of the welds.
7. The strength of the seat angle itself in bending is governed by the section modulus of a cross section of the outstanding leg.
8. The greatest tensile stress in the angle occurs directly above the point where the fillet commences, while the greatest compressive stress occurs on the fillet at an angle of from 20 to 30° with the vertical.
9. The vertical shearing distribution is not uniform on any section of the angle, and on sections near the back of the angle shows a reversal of sign. The maximum vertical shearing stress may be as high as five times the average stress over the section.

Especial thanks are due to Mr. N. G. Schreiner for assistance in performing and correlating these experiments.

CODE FOR

Fusion Welding and Gas Cutting in Building Construction

CODE I PART A
STRUCTURAL STEEL
EDITION OF 1934

Formulated by

American Welding Society Committee on Building Codes

AMERICAN WELDING SOCIETY
33 West 39th Street
New York City

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AMERICAN WELDING SOCIETY
33 West 39th Street
New York, N. Y.

Code for Fusion Welding and Gas Cutting in Building Construction*
Part A—Structural Steel

PREFACE TO 1934 EDITION

The extensive use of welding and gas cutting in the construction and equipment of buildings has brought to the AMERICAN WELDING SOCIETY numerous requests from municipal and other authorities for assistance in the formulation of regulations in the revision of existing Building Codes and the compilation of new codes where none is now in force, which will insure the safe and satisfactory use of the processes in building construction.

The successive editions of Code 1—Part A provide suitable regulations for structural fusion welding. These will be supplemented by codes dealing with other welding processes which the Committee considers suitable when properly performed. As a part of this program it is now preparing a code covering electric resistance welding, as applied to the shop fabrication of building parts.

The present edition of Code 1—Part A has been extensively revised to reflect recent advances in the field of structural fusion welding. The Sub-Committee on Revision of the 1930 Edition was composed of the following structural engineers:

G. D. FISH, Chairman.....Consulting Engineer
G. O. CARTER.....Linde Air Products Company
J. L. EDWARDS.....H. G. Balcom
F. H. FRANKLAND.....American Institute of Steel Constn.
S. H. HOLTZMAN.....Gunvald-Aus Company
J. D. MARDER.....Marc Eidlitz and Son
N. A. RICHARDS.....Purdy and Henderson
AUBREY WEYMOUTH.....Post & McCord

Among the more important respects in which the 1934 Code differs from previous editions are:

1. The allowable unit stress for compression (crushing) in butt welds has been increased to 18 kips (18,000 lb.) per sq. in.

2. Qualification tests for operators of welding equipment have been simplified and are made mandatory.

3. Filler metal is required conforming to the latest Specifications of the AMERICAN WELDING SOCIETY, in which the criteria are the results obtained with filler metal rather than its composition or method of manufacture.

4. An Appendix is included containing recommended welding practices for fusion welding.

5. A chart is presented illustrating methods of indicating fusion welds on structural drawings.

The following is the personnel of the Committee on Building Codes as constituted September 30, 1934:

MOSS, H. H., Chairman.....Linde Air Products Company
MALE, MILTON, Secretary.....U. S. Steel Corporation
ANDERSON, J. L.....Air Reduction Company
BALCOM, H. G.....Consulting Engineer
BISSELL, A. G.....Consulting Engineer
BISSELL, C. T.....National Board of Fire Underwriters
BURTON, FRANK.....Consulting Engineer
DOYLE, E. A.....Linde Air Products Company
EDER, F.....R. W. Hunt Company
ELLIS, A. R.....Pittsburgh Testing Laboratory
FISH, G. D.....Consulting Engineer
FRANKLAND, J. M.....Engineer
HOAR, W. S.....McClintic-Marshall Corporation
HUGHES, G. A.....Truscon Steel Company
LINCOLN, J. C.....The Lincoln Electric Company
LLEWELLYN, F. T.....U. S. Steel Corporation
MCKIBBEN, F. P.....Consulting Engineer
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VOGEL, ANDREW.....General Electric Company
VOM STEEG, JR., E.....General Electric Company
WHITTIER, C. C.....R. W. Hunt Company
WOOFTER, H. A.....Swift Electric Welder Company

(Signed) D. S. JACOBUS, *President*,
AMERICAN WELDING SOCIETY

SECTION 1—GENERAL APPLICATION

1. Fusion welding may be substituted for or used in combination with riveting, bolting or other connecting means specified in the Building Code,** for connecting to one another or assembling the component parts of steel beams, girders, lintels, trusses, columns and other structural steel members of buildings, or for connecting steel to wrought-iron members of existing buildings, provided that such work be designed and executed in accordance with Sections 3 to 7, inclusive, of this Code.

2. Gas cutting may be substituted for shearing, sawing or other cutting means, in fabricating or altering structural steel or wrought iron members of buildings, subject to the limitations of Section 8 of this Code.

SECTION 2—DEFINITIONS

Definitions published by the AMERICAN WELDING SOCIETY apply to welding terms used in this Code,

* Where Building Code officials desire that fusion welding and gas cutting be performed in accordance with the provisions of Code 1—Part A, without embodying it in its entirety in their own Building Code, the following citation is suggested:

Fusion Welding and Gas Cutting of Structural Steel

1. Fusion welding may be substituted for or used in combination with riveting, bolting or other connecting means specified in the Building Code, for connecting to one another or assembling the component parts of steel beams, girders, lintels, trusses, columns and other structural steel members of buildings, or for connecting steel to wrought iron members of existing buildings, provided that such work be designed and executed in accordance with Sections 3 to 7, inclusive, of the AMERICAN WELDING SOCIETY Code for Fusion Welding and Gas Cutting in Building Construction, Part A—Structural Steel.

2. Gas cutting may be substituted for shearing, sawing or other cutting means, in fabricating or altering structural steel or wrought-iron members of buildings, subject to the limitations of Section 8 of the AMERICAN WELDING SOCIETY Code for Fusion Welding and Gas Cutting in Building Construction, Part A—Structural Steel.

** *Building Code*, wherever the expression occurs in this code, refers to building law or specifications or other construction regulations in conjunction with which this code is applied.

subject to special restrictions in the use of some of the terms. A few definitions are reproduced herein, with the modifications required in some of them to suit the uses of this Code. Figure 1 (page 10) shows the application of some of the terms to typical welded joints of the fillet and butt types.

1. *Fusion Welding.*—The process of joining metal parts in the molten (or molten and vapor) state, without application of mechanical pressure or blows. Under this code, fusion welding is restricted to the electric-arc and gas-welding processes.

2. *Root.*—The zone at the bottom (or base) of the cross-sectional space provided to contain a fusion weld.

3. *Throat.*—The minimum thickness of a weld along a straight line passing through the root.

4. *Throat Dimension.*—The thickness of throat assumed for purposes of design. Under this code the throat dimension of a *fillet weld* is the altitude from the root to the opposite side of the largest isosceles triangle which can be constructed within the cross section of the weld, the equal legs lying in the fused faces. In the case of a *butt weld*, the throat dimension is the thickness of the thinner of the parts joined.

5. *Fillet Weld.*—A weld of approximately triangular cross section, whose throat lies in a plane disposed (inclined) approximately 45 degrees with respect to the surfaces of the parts joined. The size of a fillet weld shall be expressed as the dimensions of the equal legs of the isosceles triangle described in paragraph 4.

6. *Butt Weld.*—A weld whose throat lies in a plane disposed approximately 90 degrees with respect to the surfaces of at least one of the parts joined. The size of a butt weld shall be expressed as the throat dimension.

7. *Weld Length.*—The unbroken over-all length of the full cross section of the weld exclusive of the length of any craters. Under this code the length of the full cross section is termed the *effective length*, and shall be used in all specifications, calculations and drawings. In determining the effective length of a fillet weld, $^1/_4$ in. shall be deducted from the over-all length of the weld as an allowance for the rounded ends and the crater.

8. *Weld Dimensions.*—The dimensions of a weld shall be expressed in terms of its size (Pars. 5 and 6) and length (Par. 7).

9. *Gas Cutting.*—The process of severing ferrous metals by means of the chemical behavior of oxygen, in the presence of ferrous metals at high temperatures, to produce a kerf or cut of uniform width without burning the edges of the kerf or cut.

SECTION 3—MATERIALS

1. Structural steel to be welded under this code shall conform to Serial Designation A-9 (Steel for Buildings) of the current Standard Specifications of the American Society for Testing Materials.

2. Filler metal (electrodes or welding rods) shall conform to all general requirements, and to all special requirements for at least one of the four classifications of filler metal, provided by Bulletin No. 2 (revised, June 1, 1933) AMERICAN WELDING SOCIETY *Tentative Specifications for Filler Metal for Use in Fusion Welding* (see Appendix I).

SECTION 4—PERMISSIBLE UNIT STRESSES

1. Welded joints shall be proportioned so that the stresses caused therein by loads specified in the Building Code shall not exceed the following values, expressed in kips (thousands of pounds) per square inch:

Shear on section through weld throat	11.3
Tension on section through weld throat	13.0
Compression (crushing) on section through throat of butt weld	18.0

Fiber stresses due to bending shall not exceed the values prescribed above for tension and compression, respectively. Stress in a fillet weld shall be considered as shear, for any direction of the applied stress.

2. In designing welded joints, adequate provision shall be made for bending stresses due to eccentricity, if any, in the disposition or sections of base-metal parts.

SECTION 5—DESIGN

1. The architect or engineer designing or supervising welded construction shall be experienced and skilled in such work.

2. *Plate Girders.*—Girders shall be proportioned either by their moments of inertia or by the flange-area method; in the latter method, when applied to a welded girder having no holes in the web, $^1/_6$ of the web area may be considered a part of the area of each flange. Stiffeners may be either angles or flat plates, welded to the web and flanges by intermittent or continuous fillet welds designed to transmit the stresses. Connection of component parts of flanges to each other and of flanges to web shall be by means of intermittent or continuous fillet welds designed to transmit the stresses.

3. *Beams.*—The use of continuous beams and girders, designed in accordance with accepted engineering principles, shall be permitted provided that their welded connections be designed to transmit the stresses involved in continuous beam construction. At the ends of non-continuous beams, the connections shall be designed to avoid excessive secondary stresses due to bending.

4. *Columns.*—Adjacent component parts of a built-up column shall be joined by two or more lines of continuous or intermittent welding in the direction of stress, such lines to be not further apart than 30 times the thickness of metal in the thinner part. In any line of intermittent welding, the clear distance between welds shall nowhere be more than 12 in., or more than 16 times the thickness of metal in the thinner part, or more than one inch for each kip of designed strength in either adjoining weld. Fillet welding within a distance from either end of the column equal to the least width of column shall be continuous. Sufficient weld strength shall be provided to transmit the shearing stresses between joined parts caused by flexure due to long-column action, applied bending moments, and any beam reactions or other loads tending to compress the parts unequally.

5. *Butt Joints.*—One or both edges of base-metal parts to be joined by a butt weld shall be beveled if the throat dimension exceeds $^1/_4$ in., except that beveling may be omitted if the weld is to transmit only compressive stress and if the space between the parts be made wide enough to permit sound welding and if the opening be backed up by a base-metal part or by sheet metal on the side further from the welding operator. For single and double-V joints, the angle of bevel of each part shall be not less than 30 deg., and for single and double-bevel joints not less than 45 deg. The clearance between parts at the root of a beveled joint shall be from $^1/_{16}$ to $^3/_{16}$ in., except that when welding joints with heavily coated electrode, the clearance at the root may be made equal to the diameter of the electrode. Butt welds required to be beveled shall also be reinforced by making the thickness greater than the throat dimension defined in Sec. 2, Par. 4; the exposed face of a single-V or single-bevel weld shall be reinforced at least 20 per cent

of the throat dimension and each exposed face of a double-V or double-bevel weld shall be reinforced at least 12½ per cent of the throat dimension. A butt weld intended to transmit tensile stress shall be made only when one of the parts to be joined is free or is flexible enough to permit contraction of the weld metal.

6. *Fillet Welds.*—The length of any fillet weld shall be made not less than four times the weld size or else the size of the weld shall be considered not to exceed ¼ of the length for purposes of calculating strength under this code.

7. *Welds in Slots or Holes.*—When welding inside a slot or hole in a plate or other part, in order to join same to an underlying part, fillet welding may be used along the wall or walls of the slot or hole, but the latter shall not be filled with weld metal or partially filled in such manner as to form a direct weld-metal connection between opposite walls, except that fillet welds along opposite walls may overlap each other for a distance of one-fourth of their size. No slot or hole shall be less in width or diameter than 1½ times its depth.

SECTION 6—WORKMANSHIP

1. Contractors for welded construction shall give evidence of their ability to handle the required work in a competent manner. They shall prove the ability of their welding operators to produce welded connections of the required strength by having them prepare strength-test specimens conforming to the specifications in Appendix II.

2. Welding, whether in shop or in field, shall be performed in accordance with the practices recommended in Appendix III.

3. Surfaces to be welded shall be free from loose mill scale, rust, paint or other foreign matter, except that a thin coat of linseed oil, if present, need not be removed. This clause applies not only to new structures but also to cases where new steel is to be welded to members of existing structures.

4. Component parts of built-up members shall be firmly secured together, by adequate clamps or other means, in preparation for assembly welding.

5. Where parts to be joined by a fillet weld are separated more than 1/16 in., the excess above 1/16 in. in amount of separation shall be added to the weld size required by the design.

6. Structural steel shall not be painted on any areas where shop or field welding is later to be performed, except that a coat of linseed oil without pigment may be used for temporary protection. However, this clause shall not prohibit welding of steel which has been painted, provided that the paint be first completely removed from the areas to be welded.

SECTION 7—ERECTION

1. In erecting a welded structure, adequate means shall be employed for temporarily fastening the members together and bracing the framework until the joints are welded; such means shall consist of erection bolts or other positive devices imparting sufficient strength and stiffness to resist all temporary weights and lateral forces, including wind. Owing to the small number of bolts ordinarily employed for joints which are to be welded, the temporary support of heavy girders carrying columns should receive special attention.

2. In tier-building erection, members shall not be erected more than four tiers or more than two-column lengths above any column connections yet unwelded. Light structures under 30 ft. high may be erected without the use of temporary joint fastenings, provided that the members be welded together sufficiently for temporary security at the time they are erected.

SECTION 8—GAS CUTTING

1. Contractors shall give evidence of their ability to produce satisfactory gas cuts.

2. Gas-cut edges shall be smooth and regular in contour.

3. Gas cutting may be used in preparing base-metal parts for welding, provided that the edges so cut be thoroughly cleaned so as to expose a clean surface.

4. Gas cutting shall not be used to replace milling for bearing surfaces.

5. Gas cutting shall not be performed on a member while under stress, except that detail cutting to correct minor fabrication errors may be done if the removal of metal does not reduce the strength below design requirements.

6. Gas cutting of members to form openings or to remove portions of flanges shall not be done unless the design provides therefor.

APPENDIX I*

SPECIFICATIONS FOR FILLER METAL

NOTE: The following specifications are quoted from pages 4 to 10, inclusive, "Tentative Specifications for Filler Metal for Use in Fusion Welding," Bulletin No. 2, revised June 1, 1933, Report of Committee on Welding Wire Specifications of the American Bureau of Welding, adopted by AMERICAN WELDING SOCIETY.

SECTION I

AMERICAN WELDING SOCIETY SPECIFICATIONS FOR FILLER METAL (ELECTRODES AND WELDING RODS) IRON AND STEEL

Revised June 1, 1933

1. *General*

The following specifications are recommended for iron and steel filler metal (Electrodes and Welding Rods) for use in fusion welding. These specifications are primarily intended for filler metal up to 5/16-in. diameter, inclusive, and tested on base metal up to ½ in. thick, inclusive. The specifications are based on the physical properties of the weld produced by the filler metal and not on its chemical composition before use.

2. *Scope*

These specifications are recommended as covering the requirements of the AMERICAN WELDING SOCIETY Code for Fusion Welding and Gas Cutting in Building Construction, the A. W. S. Rules for the Construction of Marine Boilers and Pressure Vessels, the A. S. M. E. Boiler Code, and the usual railroad, shipyard and industrial requirements as allowed by authoritative regulating bodies, such as the American Bureau of Shipping, the

* Cited in Sec. 3, Par. 2, of this Code.

U. S. Steamboat Inspection Service, the Interstate Commerce Commission, etc.

3. *Material*

Filler metal may be made by any process that will fulfill the requirements of these specifications.

4. *Physical Characteristics*

Filler metal shall be made of commercially straight wire of uniform quality free from harmful segregation, oxides, pipe, seams or other irregularities. Wire diameter shall not vary more than plus or minus 3 per cent from that specified. Cut lengths shall not vary more than $^1/_8$ in. plus or minus from that specified. The surface of the wire shall be smooth and free from harmful scale, oil or grease and may be plain or copper finished as specified. If coated or covered, the coatings and coverings shall not be readily removable by ordinary handling and shall be of commercially uniform thickness and shall present a workmanlike appearance.

5. *Recommended Sizes of Wire and Rods*

$^3/_{32}$, $^1/_8$, $^5/_{32}$, $^3/_{16}$, $^1/_4$, $^5/_{16}$-in. diameter.

6. *Uses*

For welding of steel shapes, plates, bars, forgings, castings and other steel products covered by A. S. T. M. Specifications for material to be welded by the Fusion Process.

7. *Tests*

In the hands of a qualified welding operator, filler metal shall flow smoothly and evenly without any harmful characteristics. The welded joint and the deposited metal produced shall have the following properties listed in the two tables on this page.

8. *Inspection*

All tests shall be made at the place of manufacture unless otherwise specified, and shall be at the expense of the purchaser.

Minimum Deposited Metal Requirements as Measured on All Weld Metal Specimens

Specification Number*	Welding Positions Required†	Treatment of Specimen	Ultimate Strength, Per Cent of Base Metal Requirements, Fig. 6	Elongation, Per Cent in 2 in. Tensile Test, Fig. 6	Specific Gravity, Fig. 7
E-10 G-10	Flat	Stress relieved**	100%	20.0	7.80
E-20 E-20 GP G-20 G-20 GP	Flat F. V. & O. Flat F. V. & O.	Stress relieved**	95%	13.5	7.75
E-30 GP G-30 GP E-40 GP G-40 GP	NO TESTS REQUIRED				

*E—Welding electrodes. G—Welding rods. GP—General purpose.
†F—Flat. V—Vertical. O—Overhead.
**Stress-relieving shall be within the range of 1100 to 1200° F. for $^1/_2$ hour for $^1/_2$ in. of thickness, based on 1 hour per 1 in. of thickness. Specimen to be stress relieved before machining to size.

9. *Packing*

It is recommended that filler metal shall be delivered as specified in coils or in straight, 14- or 18-in. lengths for electrodes, and 36-in. lengths for welding rods, packed, wrapped and suitably protected as follows:

(*a*) Bundles of 50 lb. net weight.
(*b*) Boxes or kegs of 50, 100, 200 or 300 lb. net weight.
(*c*) Coils or reels of approximately 50, 100 to 200 lb. net weight.

10. *Markings*

All bundles, boxes, kegs, coils or reels shall be suitably marked and bear the following information which shall be available at destination:

Make.....
Specification No.....
Diameter.....
Net Weight.....

Minimum Joint Requirements

Specification Number*	Welding Positions Required†	Base Metal	Form of Joint, Fig. 1	Treatment of Welded Specimen	Tensile Test, Ultimate Strength, Fig. 2	Free Bend Test Elongation (Per Cent), Fig. 3	Nick-Break Test, Fig. 4
E-10 G-10	Flat	A. S. T. M. A-70 fire-box quality 55,000 lb. per sq. in. min. or equivalent or A. S. T. M. A-114 Class A marine boiler plate 60,000 lb. per sq. in. min.	Single or double V 60 to 90° included angle	Stress relieved**	100% of min. base metal requirements	30%	Not required
E-20 E-20 GP G-20 G-20 GP	Flat F. V. & O. Flat	A. S. T. M. A-70 fire-box quality 55,000 lb. per sq. in. min. or equivalent	Single or double V 60 to 90° included angle	Stress relieved**	95% of min. base metal requirements	20%	Not required
E-30 GP G-30 GP	F. V. & O. F. V. & O.	A. S. T. M. A-70 fire-box quality 55,000 lb. per sq. in. min. or equivalent	Single or double V 60 to 90° included angle	None	85% of min. base metal requirements	10%	Required
E-40 GP G-40 GP	F. V. & O.	A. S. T. M. A-7, A-9 structural quality 60,000 lb. per sq. in. min.	Single or double V 60 to 90° included angle	None	90% of min. base metal requirements	7%	Required

* E—Welding electrodes. G—Welding rods. GP—General purpose.
† F—Flat. V—Vertical. O—Overhead.
** Stress-relieving shall be within the range of 1100° to 1200° F. for $^1/_2$ hour for $^1/_2$ in. thickness, based on 1 hour per 1 in. of thickness.

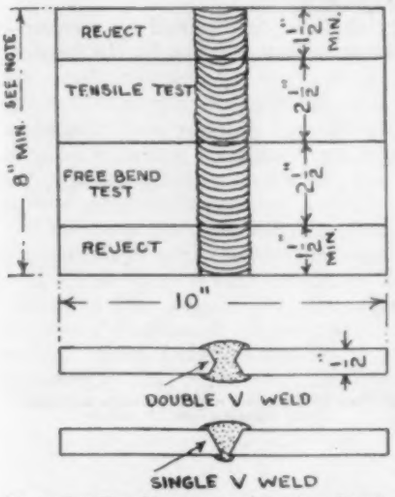
11. *Ordering*

Material ordered under these specifications shall be designated as: "Filler Metal, Iron and Steel," AMERICAN WELDING SOCIETY Tentative Specifications revised June 1, 1933.

All orders shall be specified in pounds, including coating, if any. In addition, requisitions shall show the following:

Specification No.....
Size.....

PHYSICAL TESTS
WELDED JOINT SPECIMENS



Test plates shall be so supported that warping due to welding shall not throw the finished test plate out of line by an angle of over 5°.

If plates are warped, they shall be straightened cold before being stress relieved where required.

Plates may be of such dimensions that all specimens may be made from same plate if desired.

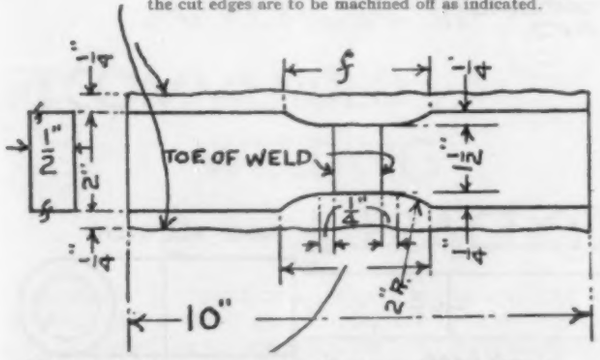
Test plates shall be welded under the procedure recommended by the manufacturer of the filler metal. For single V welds a reinforcement or wash weld is permitted on under side. Reinforcements shall not be more than 1/8 in. above surface of plate.

Both surfaces of weld to be machined flush with the plate in all cases.

Fig. 1—Test Plate Dimensions and Specimen Locations for Joint Determinations. 3 Required for Each Welding Position Specified

NOTE: When nick-break test is required, plate length should be increased to $10^1/_2$ in. to provide for specimen.

If coupons have been cut apart by a thermal process the cut edges are to be machined off as indicated.



Machining of this section should preferably be done by milling. Both faces of the weld are to be machined flush with the plate.

Fig. 2—Joint Specimen for Tensile Test. 3 Required for Each Welding Position Specified

Bend-Test Specimen.—The dimensions of the specimen shall be in accordance with Fig. 3. The length may vary with the thickness of the piece and is unimportant, provided it is long enough to permit the bending operation. The bend in the specimen may be started by holding the specimen in a vise about one-third from the end, producing an initial bend at this point with hammer blows. Another bend about one-third from the other end may be produced in the same manner.

The specimen with the initial bend at each end is then placed as a strut in a vise or compression machine and pressure applied gradually (that is, without shock) at the ends until failure occurs in the outside fibers of the bend specimen. When a crack is observed in the convex surface of the specimen between the edges, the specimen shall be considered to have failed and the test shall be stopped. Cracks at the corners of the specimen shall not be considered as a failure. The appearance of small defects in the convex surface shall not be considered as a failure if their greatest dimension does not exceed $^1/_{16}$ in.

The performance of the specimen is evaluated by measurement of the outside fiber elongation. This measurement may be made by means of a flexible scale. The elongation shall be recorded in per cent.

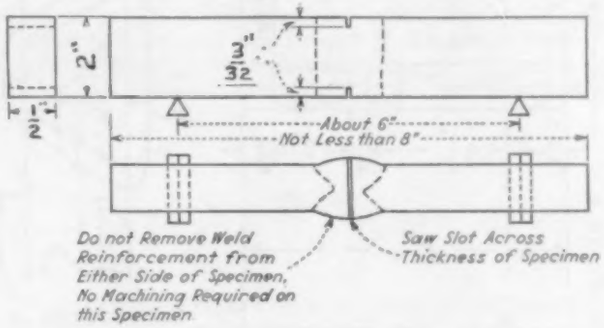

2"
3/32"
1/2"
About 6"
Not Less than 8"
Do not Remove Weld Reinforcement from Either Side of Specimen, No Machining Required on this Specimen
Saw Slot Across Thickness of Specimen

Fig. 4—Specimen for Nick-Break Test. 3 Required for Each Welding Position Specified

Nick-Break Test Specimen.—The shape and dimensions of the specimen shall be as shown in Fig. 4. The specimen is to be suitably supported as shown in Fig. 4 and broken by a sudden blow or blows applied at the center of the weld. The blow should preferably be applied by a power hammer or falling weight, and be of sufficient intensity to cause a sharp, sudden fracture of the specimen through the nicked portion.

Nick-Break Test. The nick-break test for soundness of the weld shall show in the fractured surface complete penetration through the entire thickness of the weld, absence of oxide or slag inclusions and a degree of porosity not to exceed six gas pockets per square inch

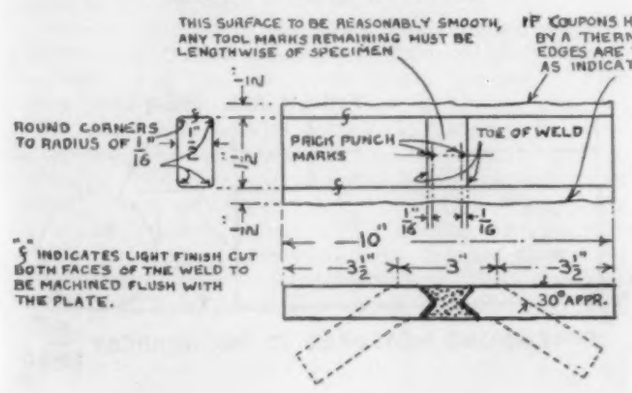

THIS SURFACE TO BE REASONABLY SMOOTH, ANY TOOL MARKS REMAINING MUST BE LENGTHWISE OF SPECIMEN
IF COUPONS HAVE BEEN CUT APART BY A THERMAL PROCESS THE CUT EDGES ARE TO BE MACHINED OFF AS INDICATED.
ROUND CORNERS TO RADIUS OF 1/16"
PRICK PUNCH MARKS
TOE OF WELD
10"
3 1/2"
3"
3 1/2"
30° APPR.
"f" INDICATES LIGHT FINISH CUT BOTH FACES OF THE WELD TO BE MACHINED FLUSH WITH THE PLATE.

Fig. 3—Joint Specimen for Free-Bend Test. 3 Required for Each Welding Position Specified

of the total area of the weld surface exposed in the fracture, the maximum dimension of any such pocket not to be in excess of $^1/_{16}$ inch.

PHYSICAL TESTS
DEPOSITED METAL SPECIMENS

The shape and dimensions of the tensile and specific gravity test specimens are shown in Figs. 6 and 7. They shall be prepared from a bar of weld metal 8 in. long. This bar shall be formed entirely by depositing filler metal between two plates as shown in Fig. 5 employing the most suitable technique. For metal arc welding subsequent layers shall not be deposited until previously deposited layers are cold to the hand. Hammering may be done for the purpose of removing scale only. The base metal used for the form shall be of the same composition as that used in any corresponding joint tests. After the bar is formed, the base metal may be removed by a gas torch or any suitable machining operation. When gas cutting is employed, care should be taken that the cut is sufficiently distant from the weld metal to avoid any heat treatment effect on the weld metal. Carbon blocks may be used in lieu of plates for preparing gas-welded specimens.

The gage lengths, parallel portions and fillets shall be as shown, but the ends may be of any form which will fit the grips of the testing machine.

NOTE: A diam. of 0.505 in. may be used if desired. This gives an area of 0.200 sq. in.

The specific gravity shall be determined by measurement and weight of the specimen and not by the immersion method.

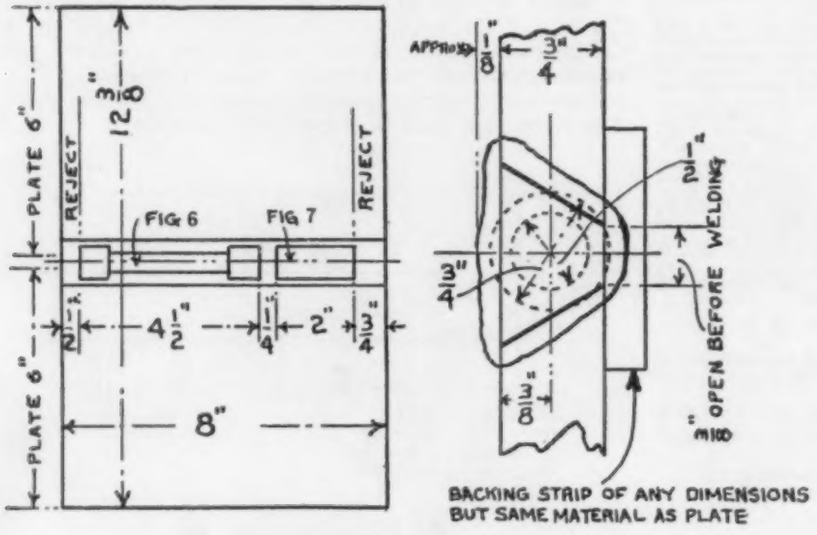


Fig. 5—Form for Depositing Metal for Tensile and Speci Gravity Tests

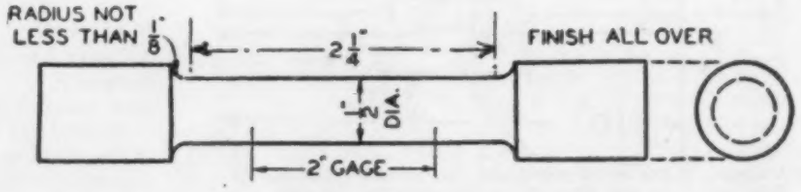


Fig. 6—Deposited Metal Specimen for Tensile Test. 3 Required for Each Welding Position Specified

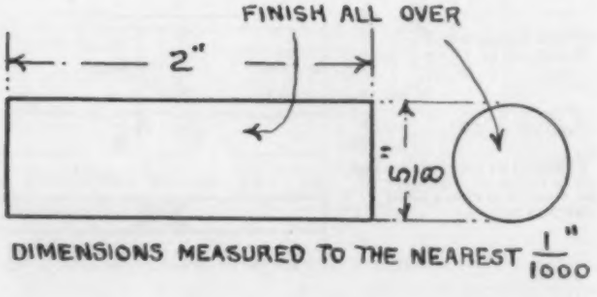


Fig. 7—Deposited Metal Specimen for Specific Gravity Test. 3 Required for Each Welding Position Specified

APPENDIX II*
QUALIFICATION TEST FOR OPERATORS OF WELDING EQUIPMENT

1. The minimum qualification requirement shall be the welding of test specimens of the type shown in Fig. 2 (page 10) and specified in Par. 2, each specimen to be tested to failure in a reliable tension-testing machine and to develop ultimate resistance not less than 80 kips. Two specimens shall be welded in the downward or flat welding position, two in the vertical welding position, and (in case the operator is to perform overhead welding as part of his structural work) two in the overhead welding position.

2. The form of test specimen shall be that which is shown in Fig. 2 (page 10), consisting of four steel bars or plates connected by four approximately equal fillet welds. This design of specimen is one of those recommended by the Structural Steel Welding Committee of the American Bureau of Welding in its 1931 report. The bar steel shall conform to American Society of Testing Materials Specification A-9. The welding edges of the splice bars shall be cut flat and square and any burrs shall be removed. The bars shall be clamped securely together and tack welded in proper position with the splice bars centered on the main bars and the faces of the main bars in true planes, in preparation for the test welding. Welding shall be performed with the same process (arc or gas), the same welding procedure, and the same kind of electrodes or welding rods to be used in the work for which the operator is being tested; the diameter of electrodes or rods shall be the largest to be used in the proposed work. Welds shall be made as nearly as possible to the designed dimensions, and in conformity with the practices set forth in Appendix III hereto; at every cross section the weld size in each direction shall be within $^1/_{16}$ in. of the prescribed $^3/_8$ in.

3. The foregoing provisions are not intended to bar an operator from further trials in case of one or more failures, or to require an operator who has passed the tests to qualify anew for every job he may undertake. Requalification is advisable after any period of several months without practice, or on changing to an unfamiliar type or size of electrode or welding rod, or at any time if decrease of skill becomes apparent. Qualification for arc welding shall not constitute qualification for gas welding, and vice versa. Qualification for welding with bare electrodes shall not constitute qualification for welding with flux-coated electrodes, and vice versa.

* Cited in Sec. 6, Par. 1, of this Code.

APPENDIX III*
RECOMMENDED WELDING PRACTICES

Appendix III explains a procedure for arc and gas welding under which sound welds are obtained, revised and expanded to embrace the current developments in both processes which have been reduced to standard practice in the structural welding field. It also illustrates the conditions which will likely ensue when this procedure is not followed.

Previous editions of the Code contemplated welding performed by the arc process using bare or lightly coated electrodes and by the oxyacetylene process. The present edition provides for the use, in the arc process, of both bare and heavily coated electrodes. In view of the trend toward the wider use of heavily coated electrodes and the general unfamiliarity of structural welding operators with their use, the section of Appendix III dealing with the procedure for welding with heavily coated electrodes is somewhat more detailed than that for bare and lightly coated electrodes. The procedure for bare and lightly coated electrodes is sufficiently well known.

* Cited in Sec. 6, Par. 2, of this Code.

The essentials of this Section, given below, have been divided into three parts: (1) General Requirements, (2) Special Requirements for Arc Welds** and (3) Special Requirements for Gas Welds.

GENERAL REQUIREMENTS

1. *Quality of Test Welds.*—Test welds, in addition to fulfilling the tensile test requirements set forth in Par. 1 of Appendix II of this code, shall fulfill the following General Requirements with regard to shape and internal quality, and shall be made in accordance with the following Special Requirements for Arc Welds, or the Special Requirements for Gas Welds, whichever process is involved.

2. *Quality of Construction Welds.*—All construction welds shall fulfill the following General Requirements with regard to shape, and shall be made in accordance with the following Special Requirements for Arc Welds or the Special Requirements for Gas Welds. Construction welds shall, in general, be at least equal in quality to the test welds made by the operator in question which satisfied the requirement of Appendix II of this code.

3. *Undersize Welds.*—Undersize or undercut welds shall be built up by welding to conform to the weld cross section called for in the drawings and/or specifications. The surface of previously deposited welds shall be cleaned of oxides or slag before any reinforcing weld metal is applied.

** The Special Requirements for Arc Welds apply to Direct Current Metal Arc Welding. Slightly different technique may be desirable when using alternating current.

4. *Rewelding.*—Welds not made in accordance with the following General Requirements for shape or the Special Requirements of Procedure, except such welds as can be corrected as in Par. 3 above, shall be chipped out or melted out with a welding flame, to sound base metal, and rewelded in accordance with these general requirements.

5. *Shape.*—The welds shall conform closely in general

FIG. 1

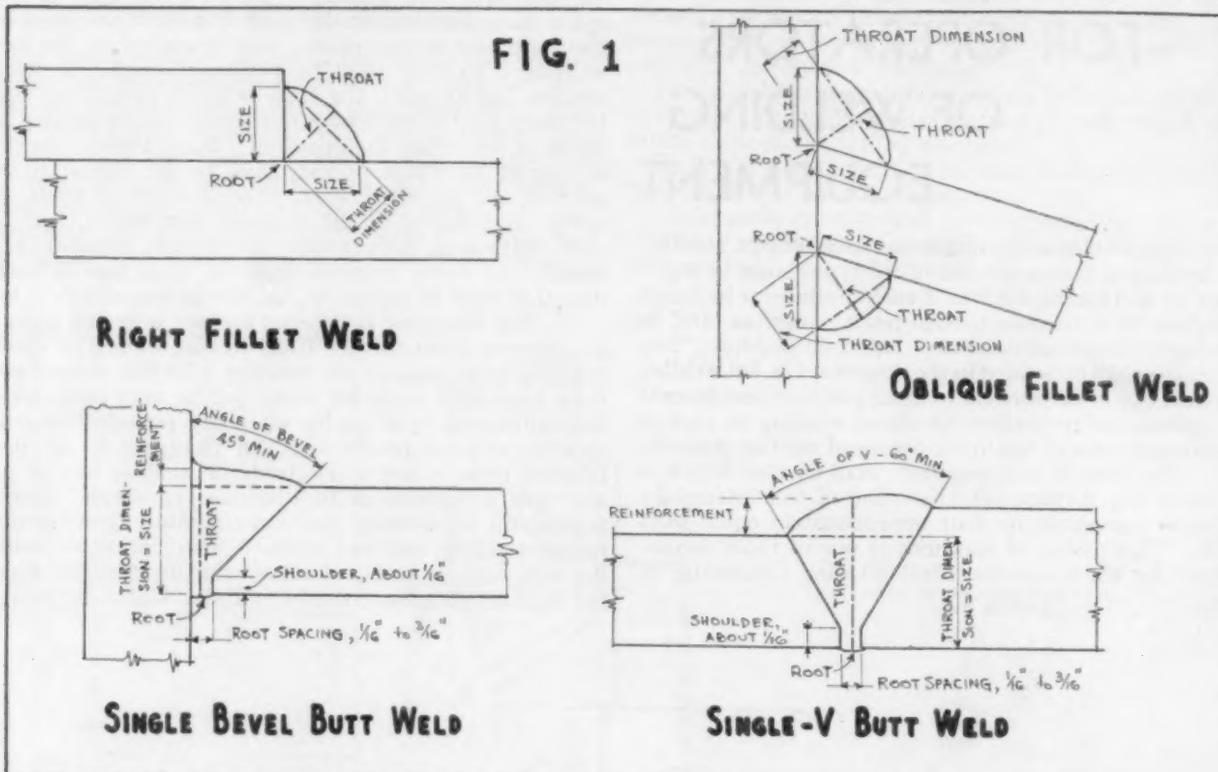


FIG. 2

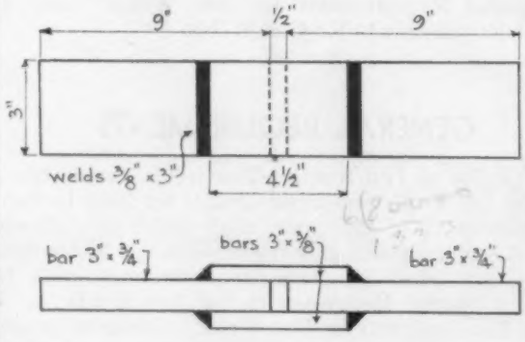


FIG. 3

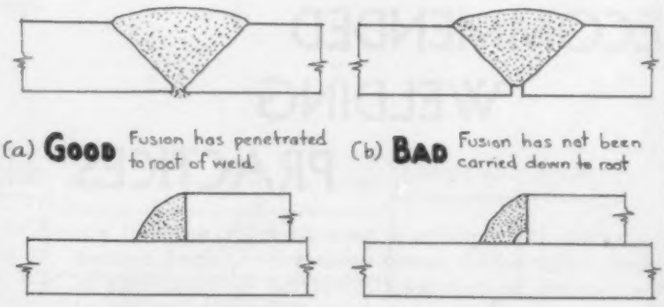


FIG. 4

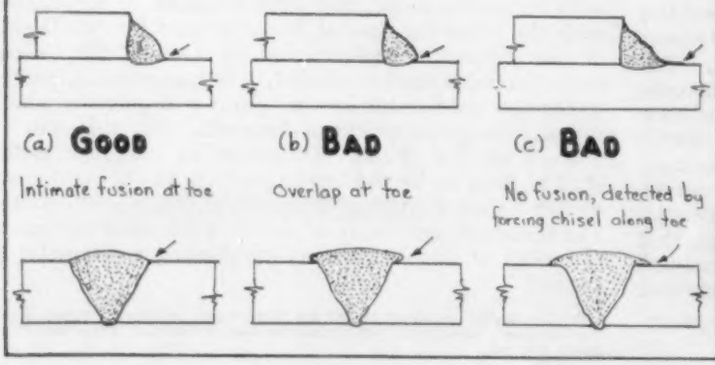
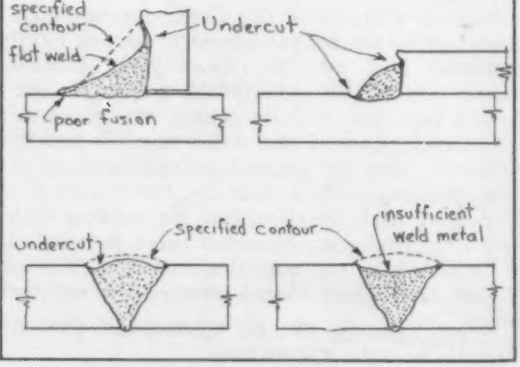


FIG. 5



shape to those shown in Figs. 3*a* and 4*a*, and shall not be undersize in any particular. Examples of welds having incorrect shape are shown in Figs. 3*b*, 4*b*, 4*c* and 5. The surface of welds shall be reasonably smooth and uniform in contour. Weld metal along the toe of the weld shall not overlap the base metal surface, but shall form an intimate contact therewith as illustrated and contrasted in Fig. 4.

6. *Internal Quality.*—The weld metal shall be sound throughout and shall be free from excessive* oxides, non-metallic inclusions and gas pockets. The weld metal shall be thoroughly fused with the base metal along all surfaces and edges of union, and shall penetrate into the root of the weld, as shown in Fig. 3*a*.

7. *Weld Ends.*—The ends as well as the body of the welds shall conform to the requirements of Par. 6.

8. *Welfare.*—While welding, the operator shall be protected from the light of the arc or gas flame by suitable equipment provided for this purpose. He shall also be provided with facilities whereby the process used may be carried on with comfort and efficiency.

9. *Visibility.*—The arrangement of the joints to be welded shall be such as to enable the operator to have an unobstructed view of the surfaces to be welded at all times during the welding operation.

10. *Tack-Welds.*—Whenever tack-welds are located where a designed weld will later be made, they shall be made according to the foregoing requirements. When encountered in the final welding operation, they shall be thoroughly fused in with the final weld. Tack-welds should be thickest at the center and should taper at both ends for convenience in carrying the regular weld over the tack-weld (see Fig. 6, page 12).

GENERAL REQUIREMENTS FOR ARC WELDS

Part 1 Bare and Lightly Coated Electrodes

Welding Arc.—The characteristics of a direct current metal arc as used in welding are indicated in Fig. 7. Unsound welds, insufficient penetration and overlap in general, result from improper arc length and/or amount of current and/or incorrect rate of travel. The characteristics of these different conditions are illustrated in Figs. 8 and 9.

Depth of Crater.—The depth of arc crater should not be less than $1/16$ in. (see Fig. 8).

Length of Arc.—In manual metal arc welding, proper fusion, penetration and soundness of weld shall be secured by using as short an arc as can be maintained for each form of weld. A typical example of proper arc length for given thickness of base metal and for a $3/8$-in. fillet weld is shown in Fig. 10. When properly manipulated, the arc will throw a steady shower of small sparks, and (in the case of bare electrodes) will be accompanied by a regular, crackling, snappy sound with fractional intervals less than one-half second between explosions. With a given current, the length of arc depends upon the arc voltage which should seldom exceed 20 volts.

Current.—The amount of current shall be such as will best suit the arrangement and the thickness of the base metals to be joined. It will vary with base metal thickness and size of electrode used. Sizes and current values that have been found suitable for Structural Welding are given in Table I. In special cases other approved sizes and currents may be specified. The current and voltage used shall be measured by suitable meters, either mounted on the arc welding machine panel, or portable, for use at the point of welding. Allowance shall be made for line drop where the meters are not adjacent to the point of welding.

Table I—Current Values and Sizes of Bare and Lightly Coated Electrodes for Various Sizes of Welds

Size of Weld, In.	Minimum Number of Layers	Electrodes and Current Values
$1/4$	1	In all these cases use either $5/32$-in. electrodes with 160–180 amps., or $3/16$-in. electrodes with 180–225 amps.
$3/8$	1	
$1/2$	2	
$5/8$	2	
$3/4$	3	

Manual Operation of Arc.—The arc shall be started by drawing a long arc momentarily to preheat base metal before deposition of filler material to insure thorough fusion at start of weld. This may also be accomplished by moving a short arc rapidly back and forward over a limited area at start.

In case of a long weld where more than one electrode is used, the arc shall be re-started about $1/4$ in. to $3/8$ in. ahead of the crater, going back over the crater to properly fill it and keep a uniform contour, thus insuring proper preheating as in start of weld.

On single layer welds the arc may progress with either a straight forward motion or an oscillatory motion depending on size of joint to be filled to bring it up to proper contour and insure proper fusion in root zone.

In multi-layer welding the first layer shall be deposited by moving the arc in a straight forward motion to secure proper fusion in the root zone, while subsequent layers shall be deposited with an oscillatory motion to build up the weld to the proper contour. The first layer shall be made with an electrode small enough to get thorough penetration at the root zone.

Each layer shall be thoroughly cleaned by brushing or chipping to remove all excess scale and oxides before depositing succeeding layers. The surface of each layer shall be reasonably smooth and uniform in contour.

Part 2—Heavily Coated Electrodes

Welding Procedure.—In making welds with heavily coated electrodes the procedure recommended by the manufacturer of the electrodes being used should be followed. However, if such instructions are not available, the procedures given below should be helpful.

Current.—The amount of current shall be such as will best suit the arrangement and the thickness of the base metal to be joined. The current ranges in Table II (page 13) are given as a guide in selecting the best operating conditions for various electrode sizes and plate thicknesses for flat, vertical and overhead welding. In special cases, other approved sizes and amounts of current may be specified. The current and voltage used shall be measured by suitable meters, either mounted on the arc welding panel, or portable, for use at the point of welding. Allowance shall be made for line drop where the meters are not adjacent to the point of welding.

*Welding Procedure for Flat Butt Welds.***—In making

* Small plates or specks of oxides are not considered harmful if widely dispersed throughout the body of the weld.

** When flat welding with heavily coated electrodes in plate thicknesses greater than $1/2$ in., it is sometimes desirable to bevel the plate edges in the form of a U.

butt welds on bevel joints, weave the electrode from one side of the joint to the other. This weaving may not be necessary on the first pass. These oscillations should be regulated so that the weld metal fuses into the side walls without directing the arc against the walls. This is accomplished by pointing the electrode downward and allowing the outer edges of the arc to play lightly on the walls. Hesitate long enough on the turns to insure complete fusion into the side walls.

The travel speed should be regulated to limit the

FIG. 6

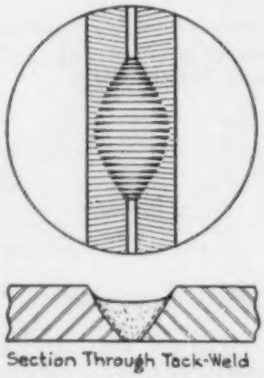


FIG. 7

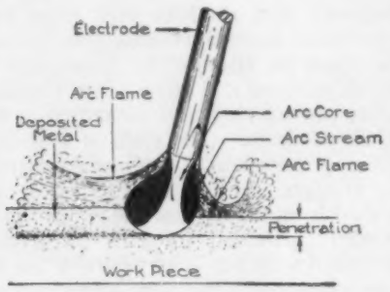
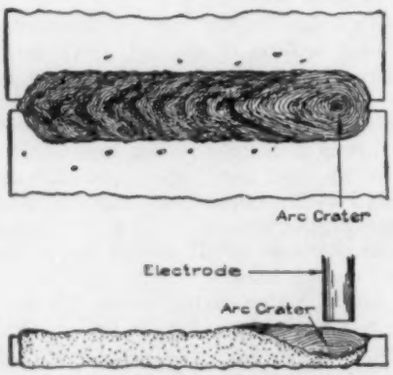


FIG. 8



Longitudinal section of deposited metal showing penetration and arc crater

FIG. 9

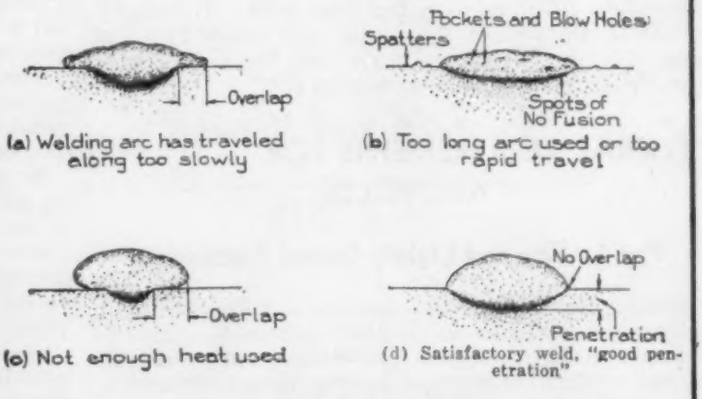


FIG. 10

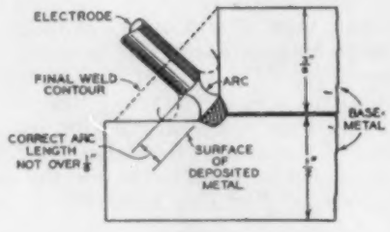
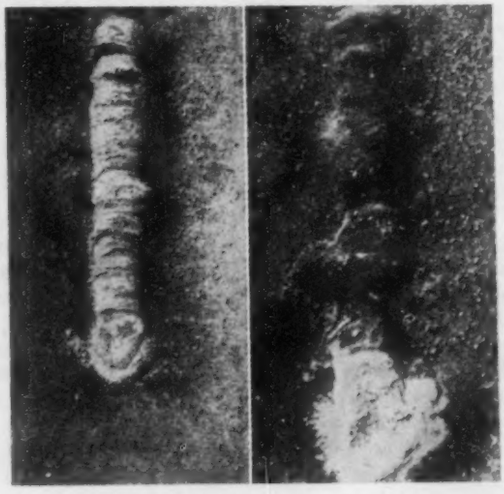


FIG. 11



A

Correct weld obtained with short arc. Note cleanness of surface

B

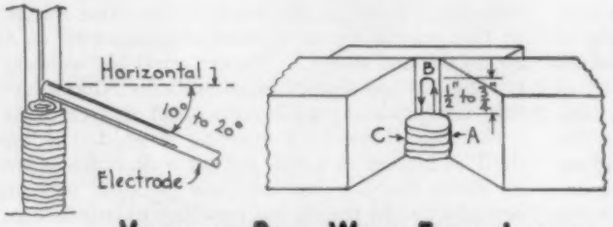
Incorrect weld obtained with long arc. Note heavy coatings of iron oxide

thickness of the layer per pass to not more than $^1/_8$ in.

Welding Procedure for Vertical and Overhead Butt Welds.—One-eighth ($^1/_8$)-in. and $^5/_{32}$-in. diameter electrodes give best results in the vertical and overhead welding positions. However, the $^3/_{16}$-in. diameter is frequently used in vertical welding with satisfactory results.

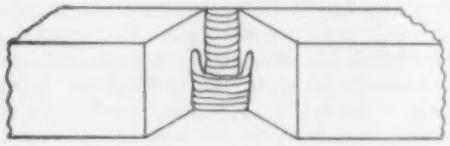
Vertical welds should be made by welding upward. The first pass is started by oscillating or weaving the electrode from side to side (Fig. 12*A*) to produce a weld

FIG. 12



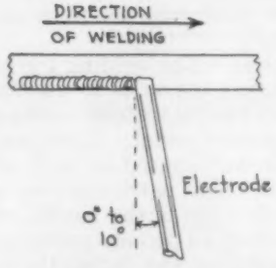
VERTICAL BUTT WELD-FIRST LAYER

FIG. 13



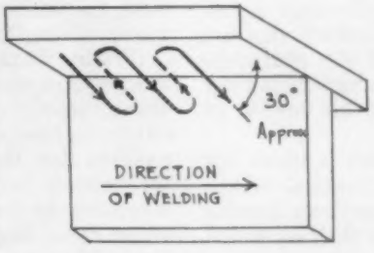
VERTICAL BUTT WELD-SECOND LAYER

FIG. 14



OVERHEAD BUTT WELD

FIG. 15



OVERHEAD FILLET WELD

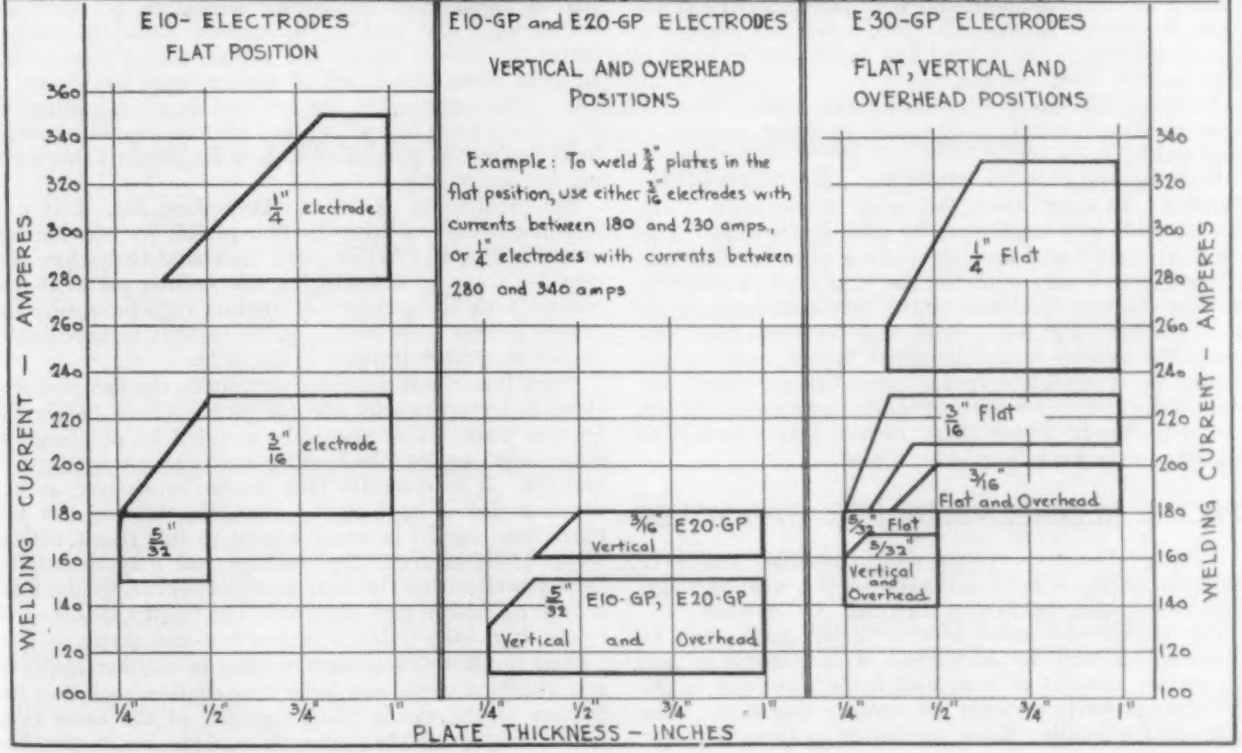
FIG. 16

ALTERNATE METHODS OF MAKING MULTI-LAYER WELDS

FLAT, VERTICAL, OR OVERHEAD FILLET WELD

TABLE II

CURRENT VALUES AND SIZES OF HEAVILY COATED ELECTRODES FOR VARIOUS PLATE THICKNESSES FOR MANUAL WELDING OPERATIONS



metal bridge across the "V." Then the arc is moved rapidly upward for 1/2 to 3/4 in. along the bottom of the "V" (Fig. 12*B*), drawing a long arc (about 30 volts), and then back down to the crater again (Fig. 12*C*), shortening the arc to its previous length. The movement up and down requires about 1/3 sec. and is very easily accomplished with a bending action of the wrist. Its purpose is to allow the molten metal in the pool to solidify and to preheat the plates ahead of the crater.

The above cycle of operation is repeated all the way up, each time depositing a thin layer of metal on top of the preceding layer. The quantity of metal deposited on each cycle will depend upon the current, ability of plate to absorb the heat, etc. The travel speed on the first pass should be regulated to limit the deposit to the equivalent of about a 1/4-in. fillet weld. On succeeding passes, the thickness should not exceed 1/8 or 5/32 in. The successive passes may be made by this up and down technique or by successive horizontal weaving.

If, in making the second and succeeding passes, a procedure similar to that of the first pass is used, the motion (Fig. 13) is across the pool or shelf, then upward and back at one side of the "V," then across the shelf to the other side, and up and back to the shelf again. The up and down motions should be done rapidly, lengthening the arc while doing so. If the procedure of weaving straight across is used, it should be similar to the above except that the up and down motion at each end of the shelf is eliminated.

For overhead butt welds, the procedure is much the same as that previously described for vertical welds. The electrode is pointed upward and sometimes leaning slightly forward, as shown in Fig. 14. A shelf on which to work is deposited at the start and the cycles of operation are the same as those for vertical welding.

Welding Procedure for Flat and Overhead Fillet Welds.—For light fillet welds (1/4 in. or less) and the first pass of multiple pass welds, the electrode should be moved only in the direction of travel. The second and successive passes or heavy single-pass welds (3/8 in. for example) should be made by weaving the electrode in a plane making an angle of about 30° with the underside of the plate, as shown in Fig. 15. The solid line represents actual welding. The dotted line represents an upward skip done in about 1/3 sec.

Welding Procedure for Vertical Fillet Welds.—Vertical fillet welds are made in the same manner as vertical butt welds.

Welding Procedure for Multilayer Fillet Welds in Any Position.—In many cases fillet welds in sizes up to 3/8 in. can be made in a single pass by holding the electrode at a suitable angle and moving it along at a uniform rate. The angle will vary with the size and type of electrode and the relative thickness of the materials forming the joint. Where the fillet weld requires more than one layer, the second and subsequent layers may be deposited as a complete spread over the previously deposited metal or in two or more parts as shown in Fig. 16. The sequence in which these various layers should be deposited may vary from case to case.

SPECIAL REQUIREMENTS FOR GAS WELDS

Welding Flame.—Torches may be either single or multiple flame. The adjustment of the welding flame shall be the same as used in the qualification tests.

The size of the inner cone or inner cones shall be regulated for varying thicknesses of base metal so that the proper amount of heat and flame condition is obtained to properly perform the welding operation. The criterion for welding flame regulation is that the inner cone or inner cones should be of a size and character which produce sufficient heat to maintain the welding puddle in a quiet molten state, and to cause fusion of the welding puddle with the base metal.

The orifice of the welding tip shall be kept clean at all times during the welding operation so that the regular and symmetrical inner cone or cones can be maintained (see Fig. 17).

Welding Rod.—The size of the welding rod to be used will depend on the thickness of the base metal, the size of the puddle being carried and the size of the inner cone or inner cones. The criterion for welding rod size is that the rod should be of sufficient diameter to maintain the welding puddle in a quiet molten state.

Starting Welds.—In starting a weld, the base metal shall be heated to a dull red for a distance of from 1 to 2 in. along the joint so that the point of welding can be brought to the fusion temperature evenly before welding rod is added. If the weld is stopped for any reason, the same precautions should be observed upon restarting.

Tack-Welds.—In making tack-welds, the same precautions should be observed as when starting welds. Where a designed weld will later be made over the tack-weld, the tack-weld shall be made with the same care as required for designed welds.

Welding Technique—General.—The welding torch and welding rod should be manipulated so as to maintain a definite puddle of molten weld metal without overheating either the base metal or deposited metal. Good practice requires that the end of the welding rod be kept within the limits of the puddle at all times, particular care being taken not to disturb the rear edge of the puddle which might cause slag on the surface to become entrapped in the weld metal. In manipulating the flame, the tip of the inner cone should preferably not touch either base metal, puddle or welding rod.

Either backhand or forehand technique may be employed. The various positions of welding rod and flame with respect to each other in backhand and forehand techniques are illustrated in Figs. 18 and 19.

In carrying the puddle forward, the base metal surfaces just in advance of the puddle should be prepared for fusion with the puddle by melting sufficient surface metal to remove oxides and expose sound base metal. In some cases this depth of melting may be 1/32 in. or less. Manipulation of the rod and flame in controlling the puddle shall be such that at no time is molten metal from the puddle permitted to flow ahead until this melting has occurred.

For welding in positions other than flat, it is permissible to carry a fairly shallow puddle for convenience in controlling it. When using backhand technique, this may be done by distributing the molten metal in the puddle with the end of the welding rod, providing the puddle is kept sufficiently molten so that surface oxides do not become entrapped in the weld.

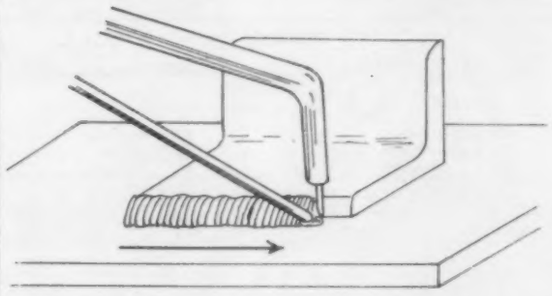
Fillet Welds.—When fillet welding in the flat position, there is a tendency for the top plate to melt before the bottom plate. This should be avoided by pointing the flame more against the lower plate as shown in Figs. 18 and 19. It is essential that fusion be secured at the inside corner or root of the joint, the welding rod and inner cone should be manipulated so this result will be secured. If desired, the welding rod may be stirred lightly, well within the bounds of the puddle, to maintain a shallow puddle and distribute the molten metal so as to obtain readily welds of proper size and shape.

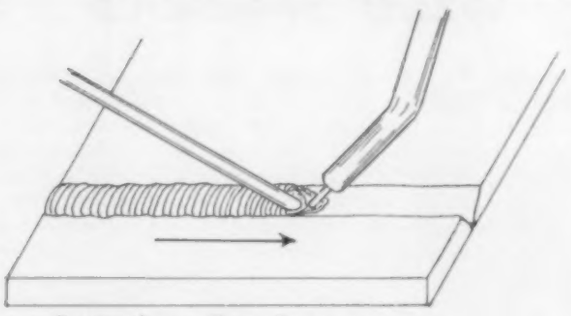
Butt Welds.—When butt welding in the flat position, manipulation of rod and inner cone shall be such that the bottom of the vee is fused together at the same time but in advance of the upper walls of the vee so that the

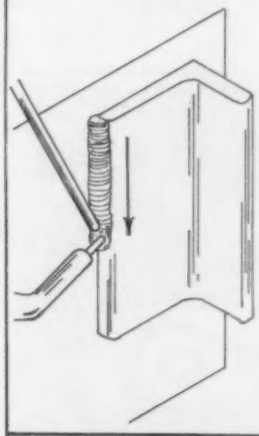
weight of the puddle does not cause molten metal to sag inside the joint. Where spacing of the joint exceeds $^1/_6$ in., it is allowable to weld the bottom of the vee together in a separate operation, $^1/_2$ in. to 1 in. at one time ahead of the principal point of welding.

Multi-Layer Welding.—Multiple layer welding may be used in place of single layer welding for all positions of welding and thicknesses of metal, but especially for welds of larger size. The usual criterion is the size of puddle that can most effectively be carried by the welder

FIG. 17
NEUTRAL OXY-ACETYLENE FLAME


FILLET WELD - FLAT POSITION


BUTT WELD - FLAT POSITION


FILLET OR BUTT WELD
VERTICAL POSITION

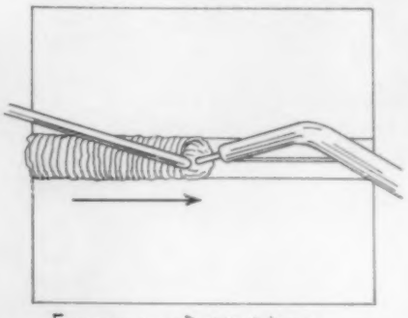
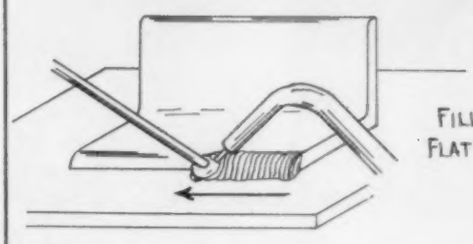
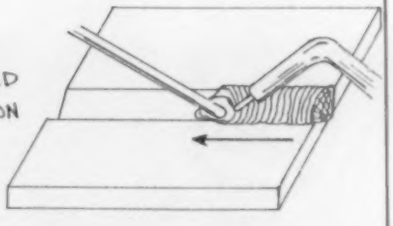

FILLET OR BUTT WELD
HORIZONTAL POSITION

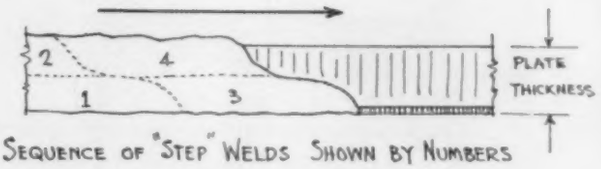
FIG. 18
POSITIONS OF ROD AND FLAME IN BACKHAND TECHNIQUE

ARROW INDICATES DIRECTION OF WELDING

FIG. 19 - POSITIONS OF ROD AND FLAME IN FOREHAND TECHNIQUE


FILLET WELD
FLAT POSITION


BUTT WELD
FLAT POSITION



SEQUENCE OF "STEP" WELDS SHOWN BY NUMBERS

FIG. 20
"STEP" METHOD OF MULTI-LAYER WELDING

for the particular position of welding. If the completion of a weld in one layer requires a puddle larger than indicated by this criterion, two or more layers should be made.

The layers of the weld may be made continuously for the full length, or the welding may be done by the "step" method illustrated in Fig. 20.

APPENDIX IV*
WELD SYMBOLS

Opposite (Fig. 21) is given a chart showing Symbols for Fusion Welding. These symbols are abstracted from the official series, prepared by the Committee on Nomenclature, Definitions and Symbols of the AMERICAN WELDING SOCIETY and approved by the Society in 1934. These symbols are applicable for the indication of arc or gas welds in drawings of buildings, bridges and other steel structures, and are recommended by the AMERICAN WELDING SOCIETY for general adoption for this purpose. Certain comments are here offered in connection with the application of these symbols for the purpose of providing them with greater flexibility, as follows:

1. Where the nature of the drawing prevents the intention of the designer from being clearly revealed by the fillet-weld symbols, it may be advisable to add the abbreviations shown on the chart.

2. Whenever fillet welds in a structure are predominantly of one size, a general note to this effect on the face of the drawings may be employed, such as "All fillet welds shall be of such and such size unless otherwise noted," thus permitting time saving by omitting the size notation wherever the prevailing size is intended.

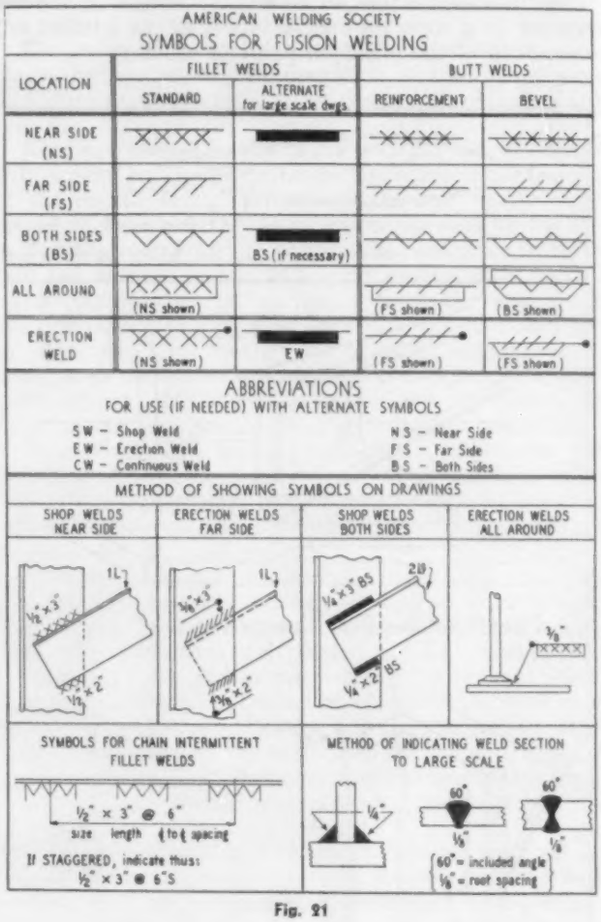


Fig. 21

* Cited in the Preface of this Code.

Tentative

Code for Fusion Welding and Flame Cutting in Machinery Construction

AMERICAN WELDING SOCIETY—MARCH 1935

Section 1. General Application

The principal field these specifications are designed to cover is that of machinery and industrial equipment where welded steel structures are substituted for gray iron or steel castings. This code does not cover pressure vessels and piping nor primary steel structures used in bridges, buildings and ships, covered by existing codes or codes in preparation.

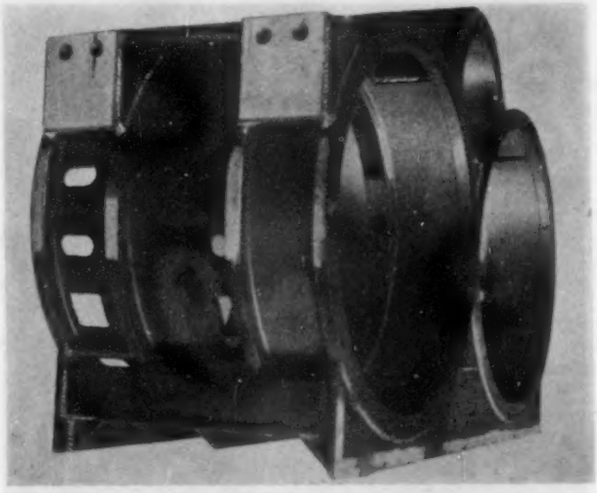


Fig. 1 (a)

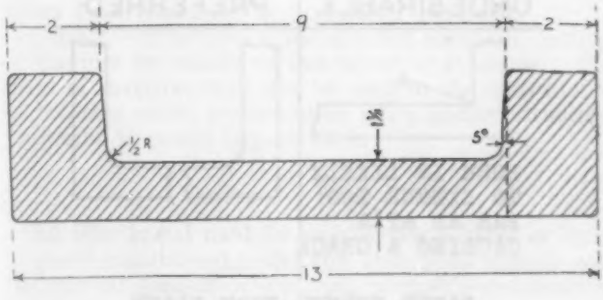


Fig. 1 (b)

Fig. 1—Special Rolled Section Used in the Construction of the Railway Motor Shown Above. This Is an Economical Procedure Where Large Tonnages Are Involved

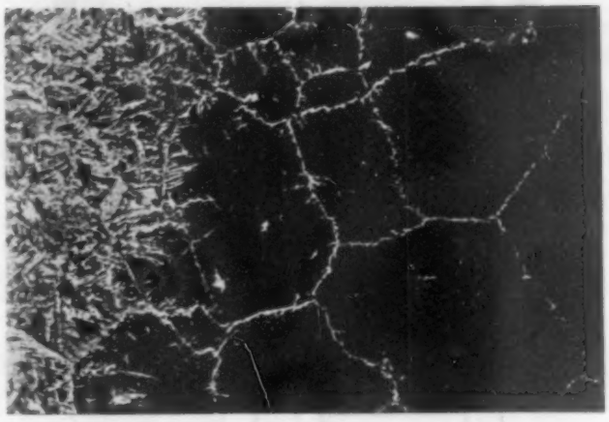


Fig. 2—Photomicrograph Showing the Boundary between the Weld Metal and the 0.40 Carbon Steel Enlarged to 200 Diameters. It Shows Severe Overheating and a Sorbitic Structure Caused by Rapid Withdrawal of Heat

Metallurgical Considerations

Particular attention must be paid to the metallurgical condition of the parent metal after welding. Figure 2 shows the damaged structure which results from welding of 0.40 carbon steel. It is a photograph of the boundary between the weld metal and the high carbon steel taken at 200 diameters. The metal has been severely overheated and in addition shows a sorbitic structure due to the rapidity with which the heavy section of the parent metal has withdrawn the heat from this zone. Due to overheating this particular structure has a low fatigue and impact resistance. It is therefore necessary to correct this condition before the structure can have a uniform strength.

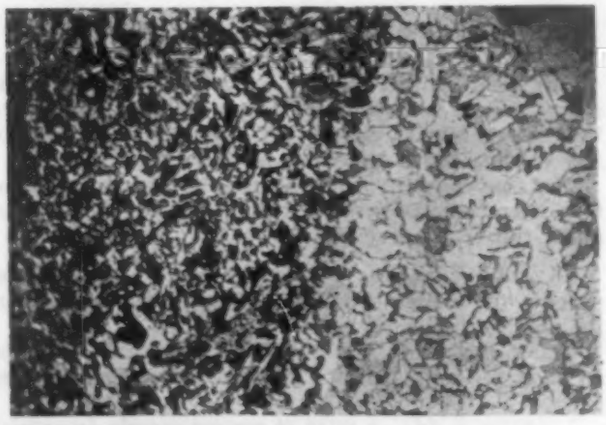
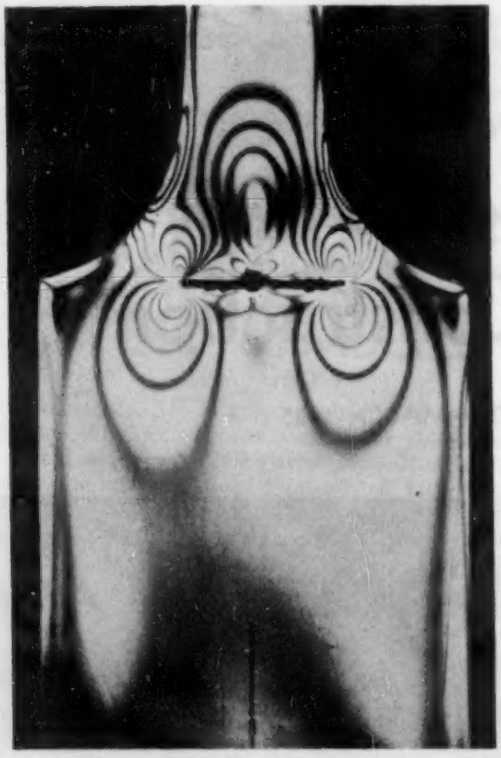
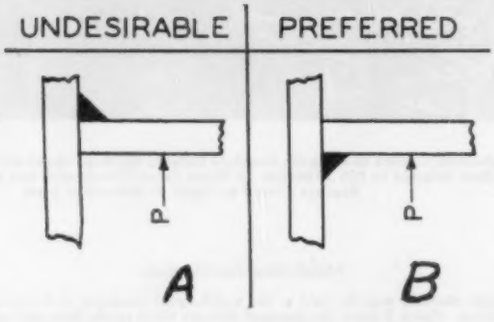


Fig. 3—Photomicrograph of Area Similar to That of Fig. 2 Taken after a Proper Normalizing Heat-Treatment. Note the Improved Metal Structure in Which the Only Physical Discontinuity Is the Change in the Carbon Content of the Weld Metal and That of the 0.40 Carbon Steel





"*A*" is a condition to be studiously avoided. The leverage acting at the root of the weld will quickly rip this joint apart. If a one-sided weld is unavoidable, it should be placed with respect to the load as shown at "*B*."

Fig. 4—Photoelastic Study Showing the Stress Distributional around a Fillet Welded Joint Subjected to Tension. The Loads Are Applied Vertically. The High Stresses Are Localized at the Ends of the Internal Boundary Formed by the Unwelded Portion

Section 2. Definitions

The definitions of welding terms as prepared by the nomenclature committee and approved and published by the AMERICAN WELDING SOCIETY shall govern for any welding terms appearing in this code.

For convenience, some of the more common terms have been included herein, and their specific applications under this code are defined as follows:

1. *Fusion Welding.*—The process of joining metal parts in the molten or molten and vapor states without the application of mechanical pressure or blows.

Under this code, fusion welding is restricted to the arc, gas, fusion thermit or atomic hydrogen-welding processes.

2. *Fillet Weld.*—A weld of approximately triangular cross section, whose throat lies in a plane disposed approximately 45 degrees with respect to the surfaces of the parts joined.

The size of a fillet weld shall be expressed in terms of the width in inches of its adjacent fused sides.

3. *Butt Weld.*—A weld whose throat lies in a plane disposed approximately 90 degrees with respect to the surfaces of at least one of the parts joined.

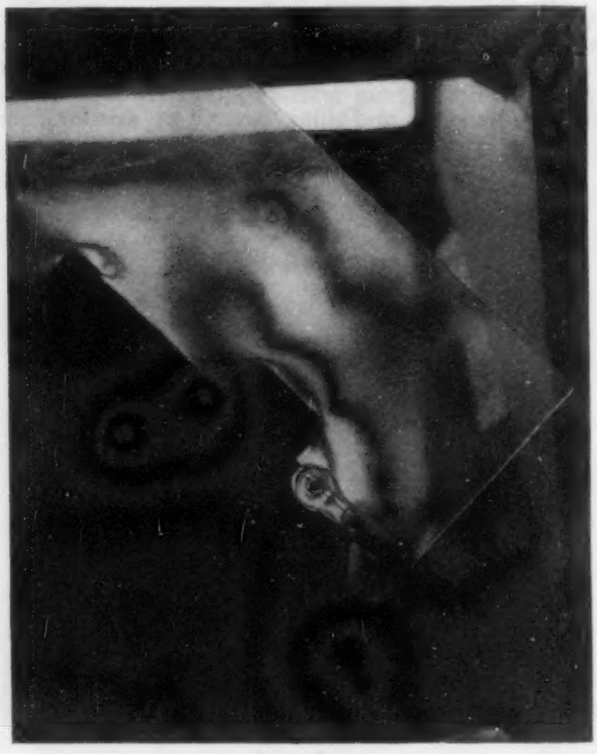
The size of a butt weld shall be expressed in terms of its net or unreinforced throat dimension in inches.

4. *Root.*—The zone at the bottom of the cross-sectional space provided to contain a fusion weld.

5. *Throat.*—The minimum thickness of a weld along a straight line passing through the root.

Under this code the throat of a fillet weld shall be the distance along a line from the root to the hypotenuse at right angles thereto, of the largest isosceles right triangle that can be constructed in the cross section of the fillet weld; and the throat of a butt weld shall be equal to the thickness of the thinner part joined.

6. *Weld Length.*—The length of a weld shall be considered to be the unbroken length of the full cross section of the weld exclusive of the length of any craters.



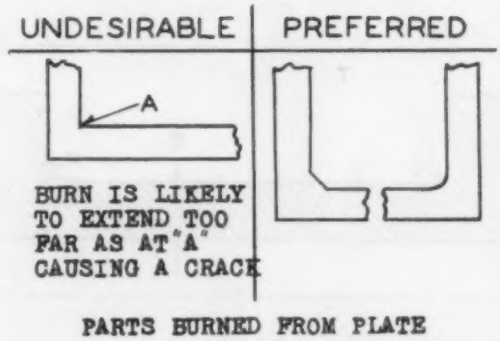


Fig. 5—The Normal Stress Distribution around the Shear Frame Shown in Fig. 6. The Stresses Are Fairly High around the Critical Contour, but They Are Enhanced Tremendously by the Presence of Notches, However Produced

Fig. 6—This Shows the Disastrous Effect of a Notch Produced by Gas Cutting at a Critical Contour. This Is an Actual Example of a Large Shear Frame Which Failed in Fatigue, Due to the Notch. Critical Contours Should Be Ground Smooth

7. *Weld Dimensions.*—Under this code the dimensions of a weld shall be expressed in terms of its size and length.

Section 3. Base Metal

In general, this code refers to carbon steels containing not more than 0.30 per cent carbon. Welding of higher carbon steels and of special alloys should be done with caution.

In many cases, where large tonnages are involved, it may be economical to use specially rolled steel shapes, in which case it is advisable to consult the mills before design decisions are made. (See Fig. 1.)

Material shall conform to one of the following classes:

Class 1.—Structures made of rolled materials, castings or forgings of known weldable composition for which a test report can be furnished the purchaser. This class of material shall be used in the construction of rotating parts, reciprocating parts and/or structures subjected to severe impact load. No restriction is placed on the chemical analysis of the base metal except as it may affect heat treatment as hereinafter provided.

Class 2.—Structures made of rolled materials, castings or forgings for which no test report is available. This class of material shall not be used in the construction of rotating parts, reciprocating parts and/or structures subjected to severe impact loads.

Section 4. Filler Metal

All filler metal used for welding for *strength* or *safety* of parts constructed under this code shall comply with the current AMERICAN WELDING SOCIETY'S specifications for filler metal E-10, G-10, E-20 or G-20.

Where alloy base metals are introduced as a part of the structure, the weld metal characteristics should be adapted to the individual requirements.

Section 5. Heat Treatment

Structures such as rotating parts, reciprocating parts and/or those subjected to severe impact load, in which safety and performance are dependent upon the welds shall be heat treated for stress-relief or stress-relief and partial grain refinement as hereinafter provided.

Structures whose functions will be affected by the subsequent warpage shall be heat treated for stress-relief or stress-relief and partial grain refinement as hereinafter provided.

When the material contains not more than 0.30 per cent carbon, the structure shall be heated slowly in a furnace, held for one hour per inch of thickness at 1100–1200° F. and allowed to cool slowly to not more than 250° F. before removal.

When the material has a carbon content over 0.30 the corresponding temperature range shall be 1425–1475° F. The higher temperature range is necessary for the higher carbon steels not only to afford stress relief but also to correct excessive grain growth adjacent to the weld. (See Figs. 2 and 3 for the metallurgical correction thus accomplished.)

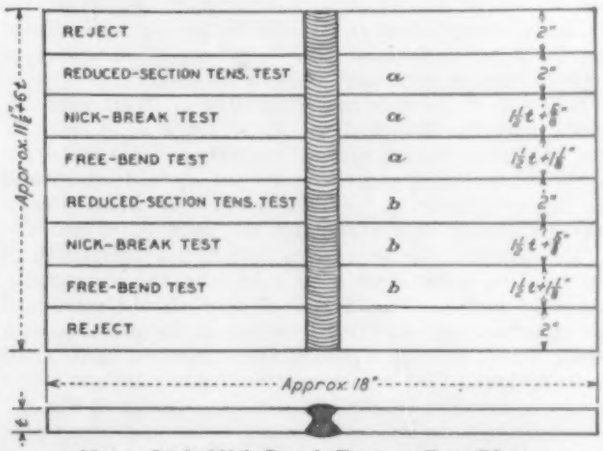
The heat treatment after welding of special alloy steels other than straight carbon steels for stress-relief and metallurgical control should be specified by the manufacturer or mill.

Nothing in this section is intended to restrict special heat treatments necessary to bring out definite physical properties.

Section 6. Permissible Unit Stresses

When A. W. S. filler metals E-20 or G-20 are used, the welds may be designed for *static* loads of 13,000 lb.

Fig. 7—Test Plate Dimensions and Specimen Locations



Note: Omit Nick-Break Test on Test Plates for Test Requirements under Par. U-70

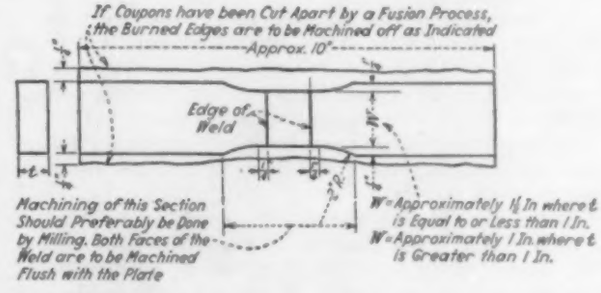
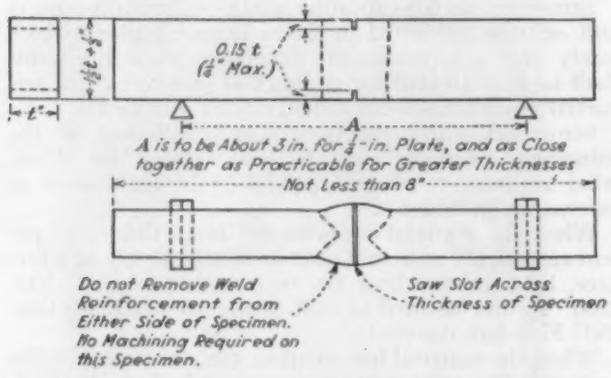

If Coupons have been Cut Apart by a Fusion Process, the Burned Edges are to be Machined off as Indicated
Approx. 10"
Edge of Weld
t
W
Machining of this Section Should Preferably be Done by Milling. Both Faces of the Weld are to be Machined Flush with the Plate
W=Approximately 1½ In where t is Equal to or Less than 1 In.
W=Approximately 1 In. where t is Greater than 1 In.

Fig. 8—Reduced-Section Test Specimen Required for Tension Test of Welded Join

Fig. 9—Specimen for Nick-Break Test


0.15 t
(¼" Max.)
A
A is to be About 3 in. for ¾-in. Plate, and as Close together as Practicable for Greater Thicknesses
Not Less than 8"
Do not Remove Weld Reinforcement from Either Side of Specimen. No Machining Required on this Specimen.
Saw Slot Across Thickness of Specimen

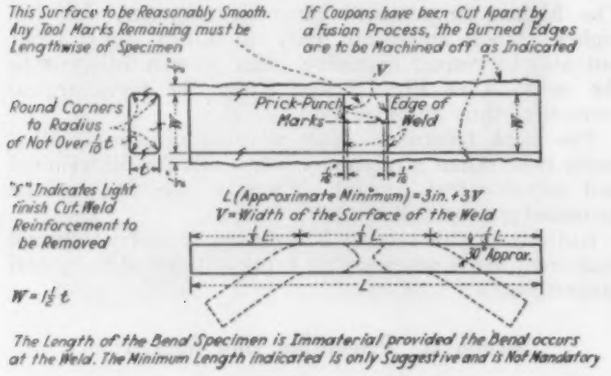

This Surface to be Reasonably Smooth. Any Tool Marks Remaining must be Lengthwise of Specimen
If Coupons have been Cut Apart by a Fusion Process, the Burned Edges are to be Machined off as Indicated
V
Round Corners to Radius of Not Over 1/10 t
Prick-Punch Marks
Edge of Weld
"f" Indicates Light finish Cut. Weld Reinforcement to be Removed
L (Approximate Minimum) = 3 in. + 3V
V = Width of the Surface of the Weld
30° Approx.
W = 1½ t
The Length of the Bend Specimen is Immaterial provided the Bend occurs at the Weld. The Minimum Length Indicated is only Suggestive and is Not Mandatory

Fig. 10—Specimen for Free-Bend Test

per sq. in. of throat area in tension or 18,000 lb. per sq. in. in compression and 11,300 lb. per sq. in. in shear, and for *dynamic* loads of 5100 lb. per sq. in. in tension or 7000 lb. compression and 3400 lb. in shear.

When A. W. S. filler metals E-10 or G-10 are used the welds may be designed for *static* loads of 15,800 lb. per sq. in. of throat area in tension or 18,000 lb. per sq. in. compression and 12,400 lb. per sq. in. in shear and for *dynamic* loads of 7900 lb. per sq. in. in tension or 9000 lb. per sq. in. compression and 5600 lb. in shear.

The dynamic values in this section are one-fourth of the rotating beam endurance values for the corresponding weld metal. This factor of four should safeguard the structure against fatigue failure in the presence of a minor defect such as a gas bubble. Welded joints shall be so designed that no severe stress concentration exists at any internal or external boundary. (Refer to Fig. 4.) This safety factor will not insure the safety of the structure in the presence of elongated defects, grooves or depressions which are loaded at right angles to their greatest dimension.

The requirements of rigidity in a structure may be such that the working stress should be only a fraction of the values specified. Where alloy base metals are introduced as part of the structure, the working stresses should be adapted to the individual requirements.

The maximum fiber stresses due to bending shall not exceed the values prescribed above for tension and compression, respectively.

Fillet welds placed either transverse or parallel to the direction of stress shall be considered as under shear.

At points of unavoidable high stress concentration, particular attention should be paid to allowable unit stresses. (Refer to Fig. 4.)

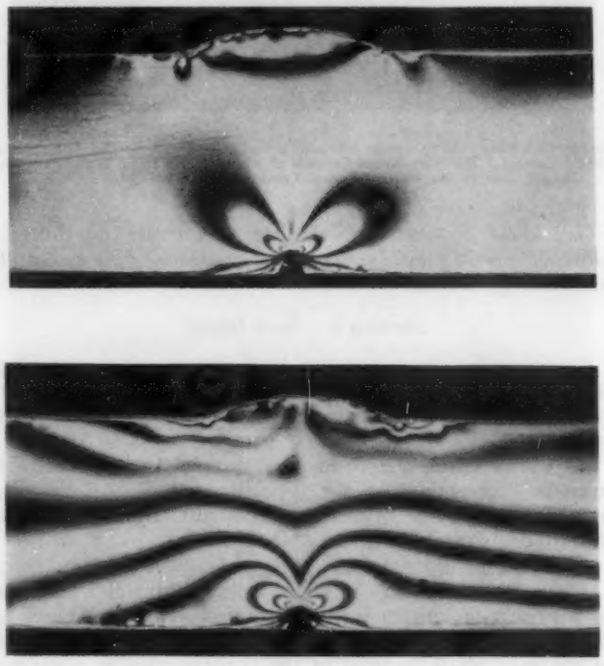
When the safety of any structure is dependent upon any weld as in the case of flywheel rims, connecting rods or crankshafts of reciprocating engines, such welds shall be fabricated with a grade of weld metal equal to or superior to the base metal. Such welds shall be radiographed to determine their soundness and shall show by such examination no slag inclusions, lack of fusion or porosity in excess of that allowed by the A. S. M. E. Boiler Code for fusion-welded boiler drums. If such welds are not radiographed, the stresses shall be 75% of the values given herein.

Section 7. Gas-Cutting

1. Gas-cut edges shall be smooth and regular in contour.

2. Gas-cutting may be used in the preparation of base metal parts for welding provided the edges so cut are left free from excessive scale.

3. Gas-cut edges at critical contours shall be ground or machined to eliminate notches. (See Figs. 5 and 6.)



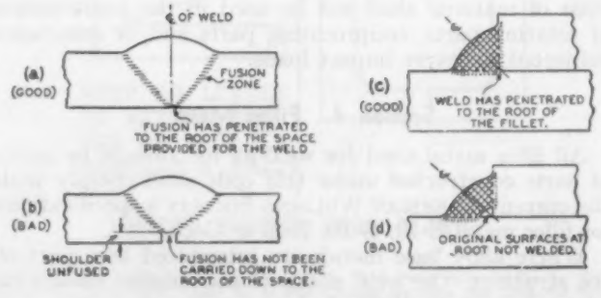
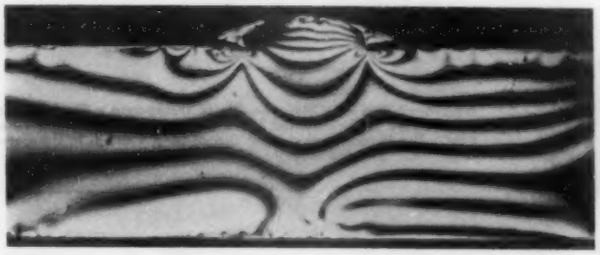


Fig. 11—FUSION. The Weld Metal Shall Be Thoroughly Fused with the Base Metal



Showing stress distribution around over-lapped weld metal

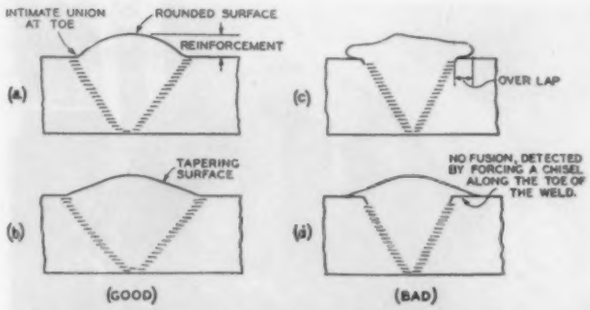


Fig. 12—CONTOUR. The Surface of Welds Shall Be Reasonably Smooth and Uniform in Contour

UNDERCUTTING. The Base Metal Along the Toe of the Weld Shall Not Be Reduced

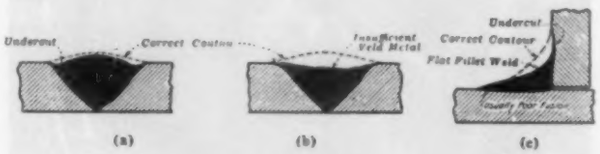
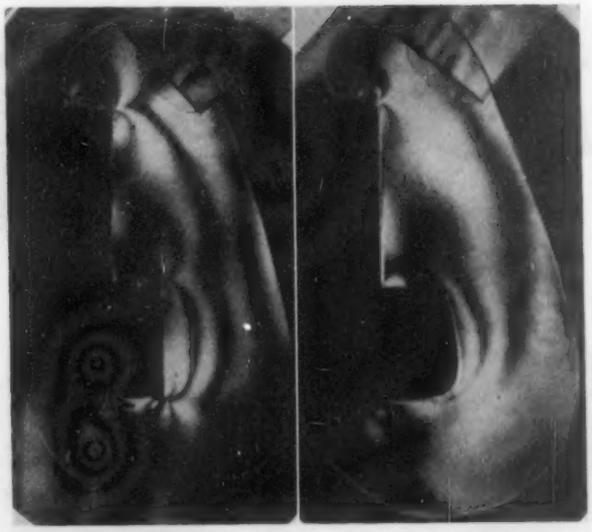


Fig. 13



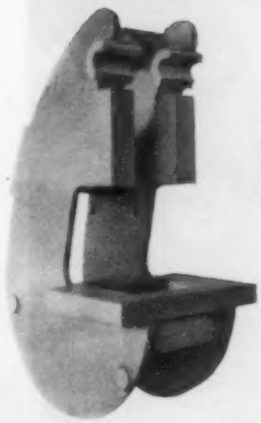


Fig. 15—Proper Design Is Important to the Success of a Welded Structure. These Photos Contrast a Proper and an Improper Contour in a Punch Press Frame. The Points of High Stress Are Starting Points for Fatigue Cracks. The Completed Press Is Shown Using the Proper Contour for the Main Frame Plates

4. Manufacturers of steel and of gas-cutting equipment should be consulted as to the proper preheating procedures when cutting special alloys and carbon steels with more than 0.30 per cent carbon.

Section 8. Qualification Tests for Operators of Welding Equipment

Each manufacturer shall be responsible for the quality of the welding done by his organization and, prior to the engagement of any operators upon the making of welds for the strength or safety of parts constructed under this Code, shall conduct tests of such operators to determine their ability to operate such manufacturer's equipment. Such tests shall require the making of a test plate weld in material the equivalent of that to be used in construction and in a thickness not less than the maximum to be used in construction except that the maximum thickness of such test plates need not exceed $1^1/_2$ in. The dimensions of such test plates, the number and the type of the test specimens shall be as shown in Figs. 7, 8, 9 and 10.

Test Results

When using A. W. S. filler metal E-20 or G-20 the

Fig. 14—Example of Fatigue Failure in a Carelessly Welded Joint. The Welder Has Left a Protrusion of Weld Metal Which Results in a Stress Distribution as Shown on the Right. This Structure Failed in Service through a Fatigue Crack Which Started at the Point of High Stress

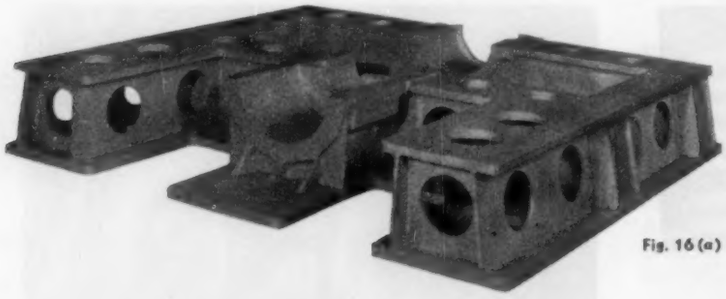


Fig. 16 (a)

Fig. 16—It Is Very Often Feasible to Incorporate a Steel Casting Subassembly in the Welded Piece in Order to Reduce the Total Cost. The Photos Illustrate This Use of Steel Castings in the Complicated Regions of the Finished Piece

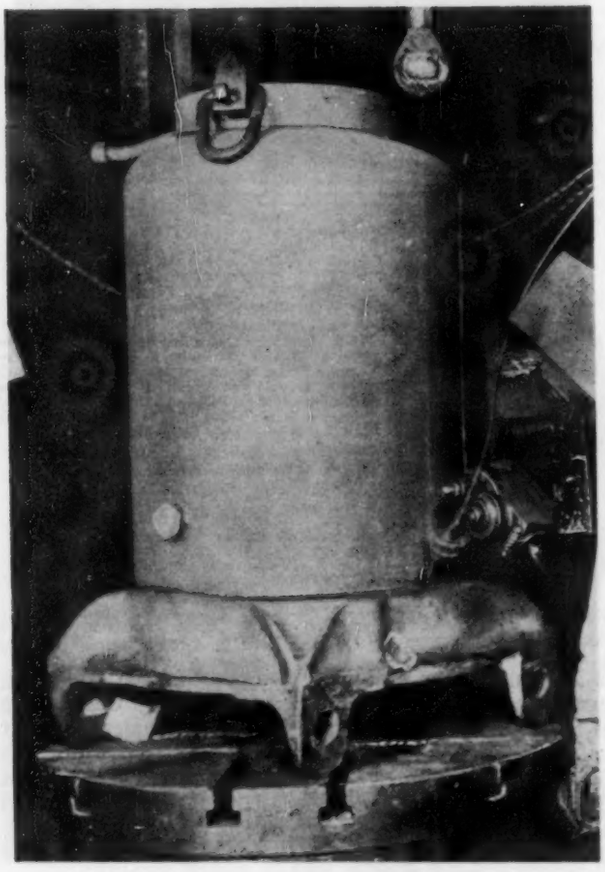


Fig. 16 (b)

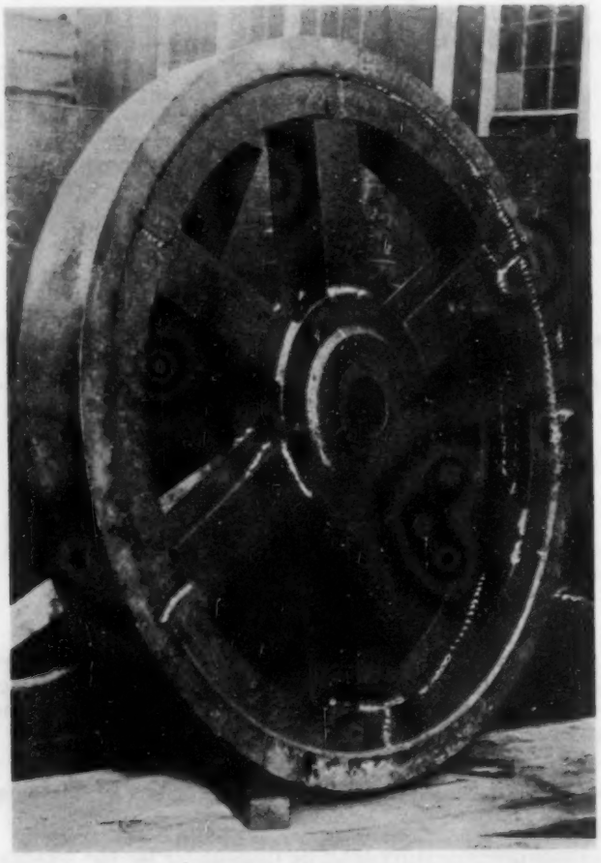


Fig. 18 (a)

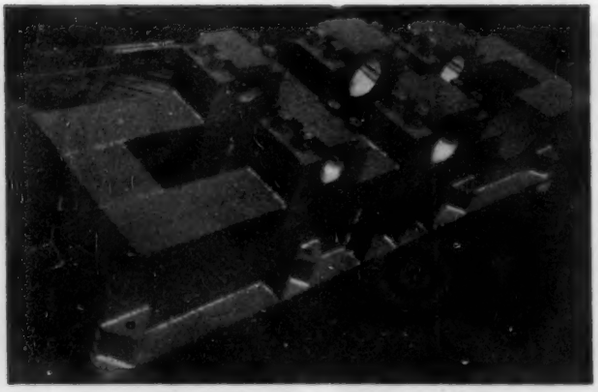


Fig. 17—This Illustrates the Use of Standard Structural Steel Shapes in the Fabrication of a Large Base

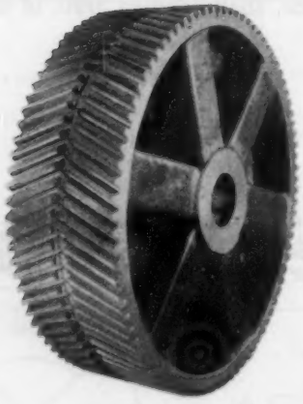


Fig. 18 (b)

Fig. 18—Gear Blanks May Be Made Either from Plates or Structural Shapes. The Above Examples Illustrate Typical Cases of the Two Methods of Design Execution

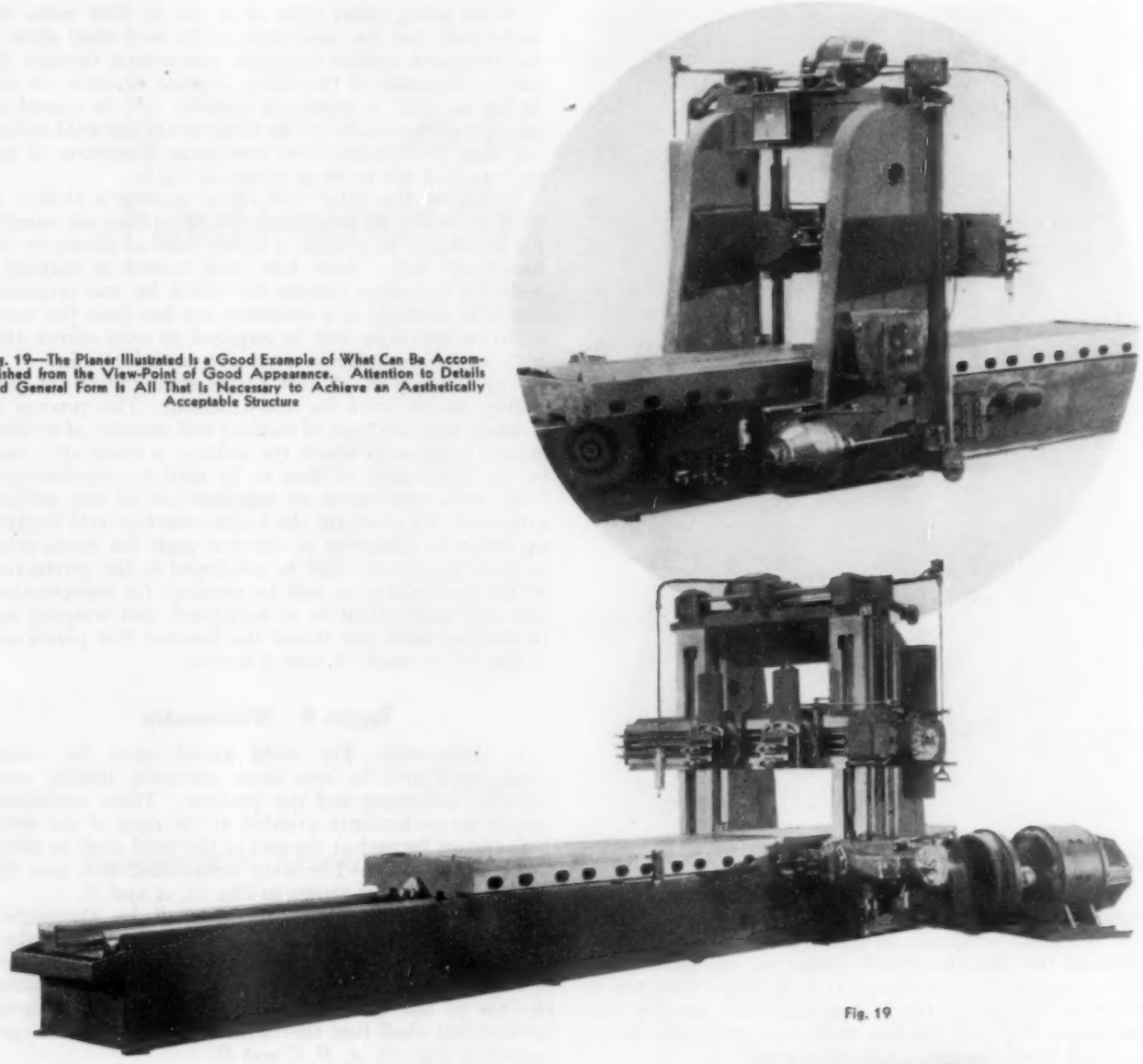


Fig. 19—The Planer Illustrated Is a Good Example of What Can Be Accomplished from the View-Point of Good Appearance. Attention to Details and General Form Is All That Is Necessary to Achieve an Aesthetically Acceptable Structure

Fig. 19

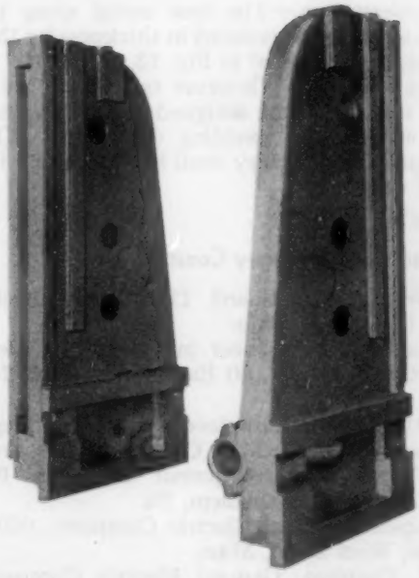


Fig. 20—The Housings of the Planer Shown Are Constructed from Bent and Formed Plates

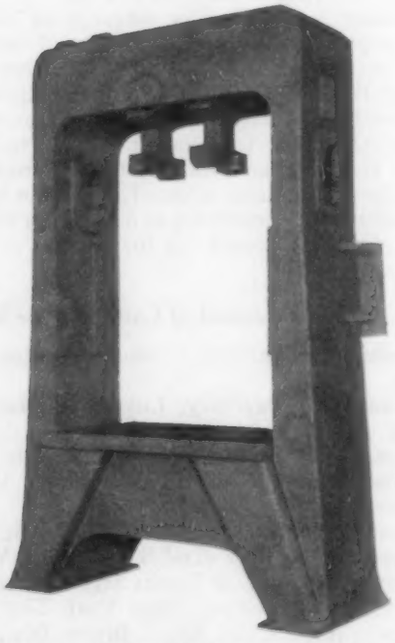


Fig. 21—Formed Plates Are the Basis of the Construction Illustrated. This Press Frame Is a Good Example of Light, Sturdy Construction Whose Appearance Is Satisfactory

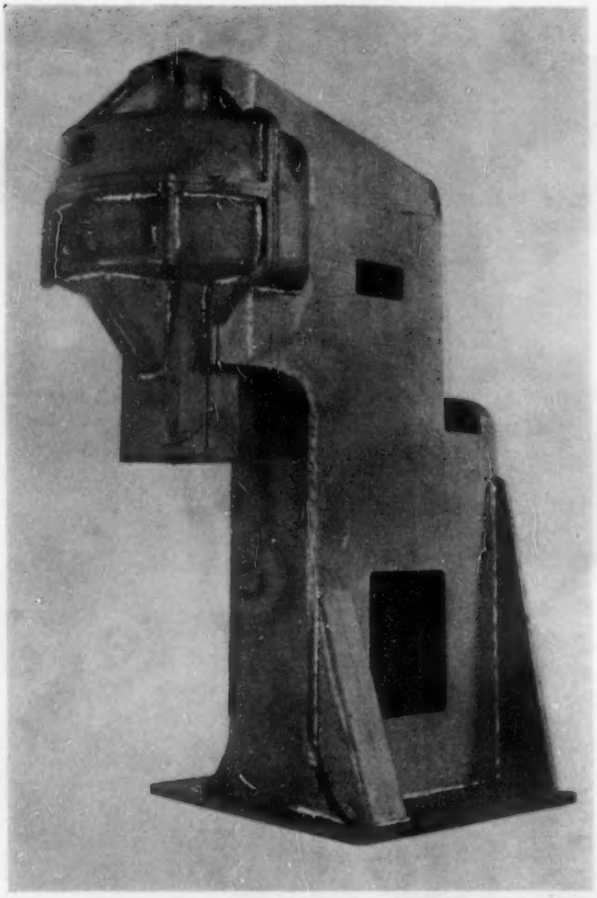


Fig. 22—Spun Boiler Heads Are Responsible for the Round Corners of the Gear Case Incorporated in This Frame. The Bent Plates Also Contribute in This Respect. Bending Is Economical Since It Eliminates Welding

tensile strength shown by the reduced section tension test specimens shall not be less than 95% of the minimum of the specified tensile range of the plate used. When using A. W. S. filler metal E-10 or G-10 the tensile strength shown by the reduced section tension test specimens shall not be less than the minimum of the specified tensile range of the plate used.

When using A. W. S. filler metal E-20 or G-20 the ductility requirements by the free-bend test method shall not be less than 20% and when using A. W. S. filler metal E-10 or G-10 the ductility requirement by the free bend test method shall not be less than 30%. In making the bend test for ductility, cracks at the corners of the specimen shall not be considered as a failure. The appearance of small defects in the convex surface shall not be considered as a failure if the greatest dimension does not exceed $^1/_{16}$ in.

When using either type of A. W. S. filler metal the nick-break test for soundness of the weld shall show in the fractured surface complete penetration through the entire thickness of the weld, absence of oxide or slag inclusions and a degree of porosity not to exceed six gas pockets per sq. in. of the total area of the weld surface exposing the fracture, the maximum dimension of any such pocket not to be in excess of $^1/_{16}$ in.

Following the initial test of an operator's ability, he shall be tested, at periods of not more than six months, for his ability to produce a sound weld as shown by the nick-break test. Such test shall consist of making a weld by the same process for which he was originally tested in material of a thickness not less than the maximum on which he will be required to weld except that such material thickness need not exceed $1^1/_2$ in.

The welding of all test plates shall follow the procedure to be used for construction. The process of welding, size and type of welding rod, number of welding layers, position in which the welding is done, etc., shall be the equivalent of that to be used for construction. Only such accessories or supplements of the welding procedure, for example, the employment of weld backing up strips or reheating of the test plate for stress relief or heat treatment, shall be employed in the production of the test plates as will be required for construction. The test plates shall be so supported that warping due to welding shall not throw the finished test plates out of line by an angle of over 5 degrees.

Section 9. Workmanship

1. *Soundness.*—The weld metal shall be sound throughout and be free from excessive oxides, nonmetallic inclusions and gas pockets. These conditions should be particularly avoided at the ends of the weld. The craters formed at the end of the weld shall be filled.

2. *Penetration.*—The weld metal shall fuse into the root of the joint, as shown in Fig. 11, *A* and *B*.

3. *Fusion.*—The weld metal shall be thoroughly fused with the base metal along all surfaces and edges of union. Multiple layer welds shall show no lamination or lack of fusion between beads. The weld metal along the toe of the weld shall not overlap the base metal surface, but shall fuse therewith as illustrated and contrasted in Fig. 12, *A*, *B*, *C* and *D*.

4. *Contour.*—The natural surface finish of welds shall be reasonably smooth and uniform in contour.

5. *Undercutting.*—The base metal along the toe of the weld shall not be reduced in thickness by the welding operation, as illustrated in Fig. 13, *A* and *B*.

6. *Tack-Welds.*—Whenever tack-welds are used, inferior in quality to the designed weld, they shall be cut out before the final welding operation. Where they are of equal quality, they shall be thoroughly fused with the final weld.

* * * * *

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A List of Fundamental Research Problems in Welding

Compiled by the

Fundamental Research Committee American Bureau of Welding

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The Bureau

THE BUREAU is the research Board of the AMERICAN WELDING SOCIETY. The Board is composed of representatives from the AMERICAN WELDING SOCIETY and from some twenty other interested engineering and scientific bodies. It has concerned itself with the promotion and coordination of research in the welding field.

Applied Investigations

Although the possibilities of welding were generally recognized a number of years ago, progress in various applications was retarded because of lack of fundamental design data and underlying fundamental knowledge on many important factors. Moreover, there was a lack of standardization as to procedures with a consequent irregularity of the resultant product. A lack of familiarity with the various welding processes on the part of regulatory bodies and engineers in general was also a contributing factor to the retardation of progress.

It was quite natural, therefore, that the first investigations of the Bureau should deal primarily with such practical problems as training of operators, standard tests for welds, welding wire specifications, technique of welding and investigations on rail joints, pressure vessels and structural steel. These investigations have brought about a uniformity of product and a decided improvement in the quality of the product. As a result of the satisfactory progress made by the welding industry, partly due to the investigations mentioned above, welding under proper restrictions is extensively used in fabricating machine parts, is permitted for use with all pressure vessels and has been adopted in the building codes of some 150 cities and municipalities.

Fundamental Researches

With the growing use of welding there is a greater need than ever before for investigations of the fundamentals. The "reasons why" of things are rarely understood and none too often sought. Again, in other instances there is a lack of fundamental design data. To meet the present needs and to foster researches of this kind, the Fundamental Research Committee of the American Bureau of Welding has been organized under the chairmanship of Mr. H. M. Hobart, Consulting Engineer of the General Electric Company. The opportunities for real service to the industry in this work are almost limitless and the possibilities of securing results of value are extremely great. Some of these problems can be best handled by the university. Moreover, in this way the teaching staff and students will become familiar with the recent developments in welding practice.

The Fundamental Research Committee comprises representative scientists of industry and also professors interested in the conduct of fundamental research work in welding. In particular, the Committee endeavors to stimulate interest in these investigations on the part of various universities. A list of problems needing investigation is compiled each year and distributed to selected universities. These universities are allowed a free hand in the selection of problems for study. The Bureau assists, when called upon, in the formulation of problems undertaken for study.

Procedure

The first step is to gain a thorough knowledge of what has already been done. The Bureau assists in furnishing selected references to published information both in this country and abroad. If requested, the Bureau assists also in indicating possible lines of attack and in supplying specimens as may be needed, made up under the conditions specified by the laboratory. Occasions to be of assistance in all sorts of ways are constantly arising.

In brief, the function of the Committee is to expedite progress and stimulate activity without in any way assuming authority or dictatorship.

In the past, the members of the Committee have assembled once a year at the time of the Fall Meeting of the SOCIETY. To make these conferences a success the Committee has raised a small sum of money to defray the railroad and pullman expenses of those professors who could not otherwise have their expenses met. Reports of investigators are published in the JOURNAL OF THE AMERICAN WELDING SOCIETY, with or without presentation before some meeting of the SOCIETY. In a few instances publication has been in other journals and presentation before other societies.

Local Branches of Committee

To expedite progress and to hold more frequent meetings of local groups interested in fundamental research in welding and to permit more active cooperation of local industries, branches of the Fundamental Research Committee have been formed in Boston, Prof. J. H. Zimmerman, Mass. Inst. of Tech., Chairman; New York, Mr. J. M. Keir, Union Carbide & Carbon Research Lab., Chairman; Pittsburgh, Mr. C. H. Jennings of the Westinghouse Electric & Mfg. Co., Chairman. Northern New York, A. Vogel, General Electric Co., Chairman; Pacific Southwest, N. F. Ward, University of Californa, Chairman; Northern Pacific A. G. Bissell, Consulting Engineer, Chairman; Chicago Jules Muller, C. H. Hollup Corp., Chairman.

List of Fundamental Research Problems in Welding

The remarks following the titles of the problems were contributed by various specialists.

Group A—Investigations Involving Physical Tests

In addition to the problems listed below many of the investigations included in the other groups are dependent upon physical tests.

GENERAL NOTE: There seems to be a general tendency in physical testing of welds to avoid impact and fatigue tests probably because of the time and expense involved in making specimens and tests. In many cases test specimens are made up blindly, i.e., without using the X-ray or some other non-destructive test before machining the specimens to determine the internal conditions of the weld. If such a preliminary examination could be made it would seem that considerable time and expense could be saved and the results of the tests would be more valuable.

1. Relation of Ductility to Other Physical Properties.

This problem, to be worked out completely, presumably would require impact and fatigue tests. Ductility does not influence static tensile strength appreciably, if at all, but has marked effect on impact and perhaps fatigue. Sufficient fatigue specimens should be provided for any one set of conditions so that endurance limit may be determined.

2. Impact Resistance of Welded Joints.

The question of the shape of specimen for impact test is the most important for this investigation. The specimens will be different for different types of joints. For any one type of weld the effect of welding procedure should be studied. At the present time there is no standard unit basis of comparison for impact strength. The result of the test will depend upon whether the impact is applied transversely with bar notched or unnotched, or in tension with weld reinforcement, if any, left on or removed. In the case of a fillet weld, obviously the result of the test will depend upon the direction of application of impact and the amount of weld tested in the specimen.

The size of the specimen has an important bearing on the impact values obtained. Its exact location in the welded joint is also important. The temperature at which the impact test is taken is another important variable. More data are needed on welds subjected to high temperatures and low temperatures and the effect of the heat of welding and various techniques on adjacent material and also different portions of the weld.

3. Fatigue Tests on Weld Metal and Butt and Fillet Welds.

(Much work has been done on welds made on low-carbon steel, therefore it is desirable that this work include alloy steels and non-ferrous metals.)

Although considerable work may have been done on fatigue testing of weld metal and butt welds, certainly it cannot be said that sufficient work of this nature has been done with fillet welds on carbon steel. If such results have been obtained they are not widely known in the welding industry. In any case the data from fatigue tests of welds are still far too incomplete for the needs of the industry. In many cases the laboratory results cannot be practically applied because of some test condition used which does not occur in actual practice. Fatigue tests of welds in the "as welded" state seem to be desirable. Similar tests on alloy steels and non-ferrous metals are also desirable. Most important, at present, is the fatigue strength of fillet welds.

Full scale fatigue tests of welded joints would be helpful in many instances.

4. Study of the Effect of Specimen Design on the Tensile Properties of Butt Welds.

(This work should be confined to specimens so prepared as to cause failure to occur in the weld or in the plane of fusion.)

Work on this problem should be directed toward the development of a reduced section tensile specimen that will give consistent and reliable results that are comparable with those obtained from parent metals with standard specimens. To accomplish this end it is desirable to investigate each specimen design by using several grades of welding because the ductility of the weld has an important effect upon the results obtained.

5. Corrosion Fatigue Tests on Butt Welds in Weld Metal.

This problem is of the standard corrosion fatigue type and needs little explanation. Complete endurance curves should be made in every case.

6. Relation between Density and Physical Properties of Weld Metal.

This problem presumably should include impact and fatigue tests as well as tensile. In connection with density of weld metal or its opposite, "porosity," the problem of rating the weld on the basis of "density" or "porosity" would be much simplified if some standard basis of rating could be established whereby the welds could be compared intelligently. The X-ray is suggested as the most accurate method of determining the amount, type and location of porosity and of other defects in the weld.

Dr. H. H. Lester of the Watertown Arsenal, X-ray metallurgist, and other collaborators, prepared a tentative classification for butt welds by which they could be rated on the basis of type, amount and location of porosity as determined by X-ray examination. This system was used to some extent for fillet welds. The work was not carried far enough to correlate physical test results with the X-ray films. Work of this sort should be done as noted in Group C (10).

7. Relation between Ductility Values as Obtained from Tensile Bend Specimens.

It has long been the practice to judge ductility as indicated by the deformation of a sample that has been tested in tension. Since many field tests have to be made on samples taken from welded joints, it is not always convenient to make the tensile test. Within the last few years, there has been developed a method of measuring ductility by observing the per cent elongation in the outer fibers of a sample that has been bent according to a certain simple procedure.

This bending method of measuring ductility nearly always gives much higher results than testing the same piece in tension. There has been no serious effort to establish the ratio between the two tests or to determine if there is a definite relationship between the tests of similar samples that have been subjected to these different tests, the samples being made by different methods of welding and on different industrial metals. This bend test has now been standardized, is used in the pressure vessel code and seems in a fair way to have universal recognition.

In order to make a conclusive report on this subject, a relatively wide variety of bend tests on welded samples should be made covering various plate thicknesses of different industrial metals, and the welds should be made by various processes. Such experiments should provide enough information to prepare an analytical treatment bearing upon the usefulness of this test and its relationship to other methods of ductility testing. Elongation determination of fillet welds is desirable and the method of testing should be standardized.

8. High and Low Temperature Tests (long and short time tests) on Weld Metal and Welded Joints.

This work is of great importance in connection with pressure vessel work where the temperatures are high. In making long time creep tests it is important to know the relative effects produced by the weld and the base metal. Two possible methods of separating these variables are: (1) vary the ratio of weld metal (width of joint) and base metal included in the gage length; (2)

study separately weld metal and base metal specimens.

9. Quantitative Studies of the Internal Stresses Caused by Welding Operation.

Probably the best way to attack this problem is to design special tensile and fatigue specimens which will contain known amounts of residual stress when welded. Varying the initial residual stresses and noting their effect upon the results of the tensile and fatigue tests will give valuable information on their effect upon welded structures. Suggested problems under this heading are:

a. Local stress-relieving.
b. Control of warpage.
c. Theoretical stress distribution in multiple-layer welds, with experimental checks on calculations.
d. Effect of layers and beads on residual stresses and warpage.
e. Complete stress map of stresses in weld and plate when single bead is deposited.

10. Proper Values of Ductility.

The new boiler code of the A. S. M. E. has placed a lower limit of 20% tensile elongation and 30% for bend test elongation for the highest quality of weld metal in Class 1 pressure vessels. There is no conclusive information available that shows the need of this highly ductile material in a welded joint, and the limit of safety has merely been set to leave the most comfortable feeling in the minds of the code designers, with the full knowledge that welding is a new industry and has to be carefully protected. This high limit of ductility is obtainable only by the very highest type of factory practice, and a good portion of the industry is inclined to look upon it as providing a monopoly to certain manufacturers.

The question naturally arises whether this is an economic waste, and whether this limit of ductility may be decreased without affecting safety. The investigation proposed is to develop and carry out carte blanche a series of tests that will provide positive information on this much debated question.

It is suggested that coupons be cut from vessels which have performed satisfactorily in service, and tested in comparison with newly prepared samples of welding made by bare wire (electric), covered wire (electric) and gas. It is suggested that these studies also include medium carbon and alloy steels.

11. A Study to Determine the Relative Effect of Stress Concentration in Welded Nozzles Due to Relation between Size of Nozzle Opening, Size of Header and Wall Thickness.

Certain tests have been conducted along this line on full-size welded details, measurements being taken with strain gages in an attempt to develop some relationship between the three factors above mentioned. The results of the tests conducted so far are inconclusive, and if a photoelastic study could be made for the purpose of investigating the relationship of these factors, it would be of considerable value in helping to determine the conditions under which nozzles should be reinforced and the design of this reinforcement.

12. A Study to Determine the Relative Stress Concentration of Welded Flanges of the Screwed-on and Seal Welded Type *vs.* the High Hub Butt Welded Type.

Since the introduction of the high hub butt welded flange, the welding industry has gradually been working away from the use of the screwed-on and seal welded type of flange. There are still, however, a good many users who are continuing to employ the screwed-on and seal welded flange, and it is felt that the result of such an investigation would do much to bring out the superiority which has been claimed for the butt welded flange. This problem might be amenable to photoelastic treatment.

13. A Study of the Relative Stress Transfer in Nozzle Openings in Pressure Vessels of Riveted and Welded Construction.

This investigation might undertake to determine the relative stress transfer between the normal pipe nozzle connections used in welded construction *vs.* the flanged type connection used in riveted construction. The purpose of this investigation would be to determine the relative stress transfer between welded connections of this type and equivalent connections designed for riveted attachment. If this problem could be treated by photoelastic methods, it would undoubtedly provide more reliable information than by some other mechanical testing method.

14. The Nature of Fracture in All Types of Weld Metal.

There is considerable fragmentary information on this subject scattered through the literature of recent years, but no complete and comprehensive investigation has been made of all types of tests on all kinds of deposited metal.

The investigation should examine all known types of welds by subjecting them to fracture by all the principal types of stresses. Careful microscopic examination should be made of the fractured areas with a view to determining the characteristic fracture of different metals subjected to different tests.

The experienced metallographer will find much of interest in these studies and, if carried out in a fundamental character, much new information will undoubtedly be forthcoming.

Group B—Involving Considerable Metallurgical Experience

(*See other Groups, particularly Group D*)

1. Relationship of Nitrogen and Oxygen Content of Welds and Their Physical Properties.

Nitride needles are considered to have an important effect upon the ultimate strength and the ductility of welds. (Much evidence in support of this fact has already been obtained.) Consequently, it would be valuable to have a direct correlation between nitrogen content, ultimate strength and ductility.

This problem is important because of the increased use of the electric arc welding process. There is no doubt that nitrogen is somewhat harmful but there are also some beneficial influences due to the presence of this element in weld metal.

The problem involves, first of all, a comprehensive review of all literature on the subject of nitrogen in iron and steel, its cause, factors influencing the extent of nitrogen absorption and physical properties modified by such absorption. It involves also a review of all literature on nitrogen in weld metal with methods of control.

The investigation in the laboratories will start with methods of controlling the amount of nitrogen absorbed in electric arc welding. This part of the investigation is, by itself, very important to the industry.

Having developed methods of controlling the amounts of nitrogen, the investigation will then deal with the properties of weld metal with varying amounts of nitrogen.

2. Effect of Heat of Welding on the Adjacent Materials with Particular Reference to Various Alloy Materials.

Nearly every type of plain carbon and alloy steel has been welded with more or less success. The results obtained, however, are not always entirely satisfactory because of the change produced by the heat of welding in the base metal adjacent to the weld.

When welding chrome nickel steels there is danger of carbide precipitation which reduces the resistance of the

affected metal to corrosion but does not affect its strength. Welding certain chrome alloy steels causes grain growth which affects the strength of the metal. When welding manganese steels there is danger of annealing the austenitic structure and producing a hard brittle zone. The heat produced in welding malleable iron sometimes reduces the parts adjacent to the weld back to cast iron. When welding high-carbon steels some of the carbon may be burnt out, thereby reducing the strength of the joint.

In studying the effect of welding heat on the metal adjacent to the weld, two objectives should be kept in mind: first, find out what effect is produced; second determine how these effects can be corrected either by changing the welding procedure or by subsequent treatment.

For pearlitic steels the problem may be subdivided as follows:

a. Determination of a heat-treatment, which may be called the "weld quench," which simulates the effect of the welding heat on the adjacent base metal, just next to the bond. This is the critical point in studying pearlitic steels, since it is the point of maximum hardness. As plate thickness and heat input will affect the weld quench, their relation should be investigated, plotted, and some standard rod-size, amperage, arc length and plate thickness chosen for the future work.

b. Study of alloy series varying by only one element, such as carbon, manganese, silicon nickel, vanadium, molybdenum, chromium, tungsten. Determinations of hardness and bend ductility should be made.

c. Effect of preheat temperature on hardness produced during the weld quench, and arrangement of alloys into groups depending on the preheat required to maintain a standard of bend ductility adjacent to the weld.

d. Effect of Flame Cutting as Compared with Other Methods of Cutting and Shearing on the Properties of Welds Deposited in Various Compositions of Steel.

e. The Technique of Hardening Welds by Carburizing and Nitriding.

f. The Use of Oxyacetylene Flame for Local Heat Treatment. Depth and Area of Hardened Zone with Various Thicknesses of Material in Spot Hardening.

(*a*) Types of steel.
(*b*) Effect of air hardening.
(*c*) Effect of water hardening.

Repeat for straight line hardening and also for closed circle heat treatment, making for the latter a study of the end effect and general technique.

3. Effect of Annealing in Hydrogen Atmosphere on the Physical Properties of Welds.

There are many investigators who believe that hydrogen annealing will not be beneficial in improving the quality of welded joints. This is based upon the fact that hydrogen only penetrates metals at a very slow rate and would not be of great commercial usefulness.

To settle this point a series of annealing treatments imposed upon welded samples, made by different processes and in different materials, should be carried out. The ordinary type of tensile and bend tests should be conducted and impact tests should be made on samples having weld metal across their middle. It might suffice to hydrogen anneal the whole solid plate at the most favorable annealing temperature, this plate being then cut up into the samples above suggested. On the other hand, the investigator might consider it necessary to hydrogen anneal some of the samples after cutting from the plate. This would be a matter for the investigator to decide, depending upon the results to be obtained.

4. Study of Systems. The study of the systems: Fe–FeO; Fe–MnO; Fe–N–C; Fe–FeO–N; Fe–FeO–C, N should be of considerable interest to the metallurgy of welds.

Because of the very profound effect of small amounts of oxygen and nitrogen on the physical properties of steel, and because of the possibility of the presence of finely dispersed non-metallics such as MnO and FeO when oxygen is present, it is highly desirable that the knowledge of the phase relationships of these elements together with iron and manganese be increased.

Mathewson, Spire and Milligan on p. 66 of Vol. 19 (1931) of Trans. Am. Soc. for Metals, deal with this effect with respect to iron and oxygen.

5. Effect of Various Alloying Elements in Steel Plate on Properties of Weld Deposit.

Items such as nickel, manganese, silicon, chromium, vanadium, etc., should be considered, and combinations of them.

6. Materials for Making Spot and Seam Welding Electrodes.

7. Surface Condition of Steel. It is suggested that the surface condition of steel caused by cold rolling has some effect on penetration in arc welds, resistance welds and in copper brazing. The causes should be studied in a wide variety of steels.

8. Effect of pickling of parent metal on the quality of the weld.

Group C—Problems in Physics

1. Laws Governing Magnetic Disturbances in A.C. and D.C. Arc Welding and How the Latter May Be Overcome.

One of the greatest difficulties encountered in arc welding is magnetic (arc) blow. Although a great deal has been done in connection with the control of arc blow, investigators are still far from the solution of the problem. This problem requires investigating into the fundamentals of magnetism and the theory of the arc.

Library Research will be of considerable value in connection with this problem.

2. Magnetic Characteristics of Various Types of Welded Joints for Use in Electrical Machines.

3. Metal Transferred in Different Positions during Arc Welding (A.C. and D.C.).

NOTE: Dr. Dushman states: "I have seen some experiments on inverted welding in which, apparently, the iron was transported from the welding rod to the welded material as a vapor. I could not see any evidence of transport of iron by sputtering and there was certainly no transport by actual contact of the fused end of the rod. Now, by comparing the amount of material transported under those conditions, for a given current density at the cathode, with the amount transported when the welding is carried out at the same current density in the usual manner, it should be possible to obtain some idea regarding the relative amount of iron transferred by evaporation and mechanical sputtering or fusion."

Mr. Hobart states: "It would be instructive to have oscillograms for flat welding and inverted welding with the same volts and amperes in both cases and all other conditions the same. For flat welding we should presumably find several short circuits per second which some would ascribe to the metal being transferred in drops, one drop per short circuit. For inverted welding these short circuits might be absent.

"Many other comparisons could be made using this same general line of attack."

Prof. G. E. Doan states that some investigators attribute the upward transfer of metal to the "pinch effect." Mr. Doan believes that this matter has been answered

by German studies of inverted welding. Another investigator has shown oscillograph records indicating short circuits in overhead welding caused by transfer of metals in globules. Others attribute transfer to explosion of gases in ordinary electrodes. (Report now being published.)

4. Comparative Arc Behavior with Iron Electrode in Argon, Nitrogen and Air with Arc Formed by Electrode Containing Slag and Oxide.

GENERAL NOTE: From the standpoint of arc behavior the question of melting rates of various electrode materials seems to be of some interest. A study of the effect of arc conditions and various elements in the electrode on the melting rate may lead to some definite conclusions regarding arc phenomena. This study could be made in conjunction with Problems (6) and (7).

There is also the question of the effect on arcing characteristics of various elements on the surface of the electrode and the effect of these elements on the melting rate of the electrode. This problem is suggested as an elaboration of (4).

NOTE: Dr. Dushman states: "There is distinct evidence that the stability of the arc depends upon the presence of small amounts of oxide on the surface of the cathode. For this reason, I would like to see experiments in which attempts are made to carry out welding with electrodes which are thoroughly free from oxide and, furthermore, if possible, these experiments should be carried out in an atmosphere of argon in order to avoid oxidation."

5. Effect of Electrode Containing Cobalt and Nickel on Behavior of Arc. (See Note above.)

It would seem desirable to include also other alloying elements such as chromium, manganese, vanadium, tungsten, etc., to determine their effect on arcing characteristics of the electrode.

In addition to the effect of alloying elements on the arc, the effect of single-constituent coatings on the arc would be useful. This could later be elaborated to include the effect of two compounds, etc.

6. Motion Pictures of Metal Transference in the Arc.

Motion pictures of metal transfer are of extreme value in connection with the theory of the arc. Such pictures must be taken at very high speeds in order to be of real value. Consequently this work would require expensive and special equipment. Motion picture studies of arc welding in the vertical and horizontal planes would throw new light on these subjects.

7. Calorimetric Study of Carbon and Metal Arcs.

This study would be of great practical value if the heating effect of various arc conditions on the material being welded could be determined quantitatively with reference to the amount of energy used. Such results might lead to methods of predetermining amounts of expansion and contraction by mathematical analysis.

8. Temperatures of the D.C. and A.C. Iron Arcs in Air and Other Gases.

9. Non-Destructive Tests of Welds.

Correlation between X-ray photographs and the actual strength of welds.

Further refinement of the use of gamma rays for weld examination.

Investigation of the vibration method of testing the soundness of welded joints.

Investigation of electrical and magnetic methods of weld testing with particular reference to fillet welds.

10. X-ray Study of Crystal Structure of Welds.

The application of the X-ray diffraction methods to the study of welds covers a wide range of problems. The first group involves the determination of the atomic arrangement in the weld metal and an accurate measurement of atomic spacings. This information leads to conclusions about the way in which various elements occur in the weld metal, that is, as solid solutions or in the form of compounds and, as far as it is possible, the rôle which each plays in determining the physical properties of the weld metal. The second group of problems has to do with the important effect of grain distortion upon the properties of weld metal. The paper, "On the X-ray Determination of Stress in Welds," published in the Sept. 1932 issue of the JOURNAL OF THE AMERICAN WELDING SOCIETY, gives a general picture of the problems of this group and points out that there is much to be done in this field.

11. Temperature of Oxyhydrogen-Carbon Monoxide Flame with Various Ratios.

12. Temperature of Oxyacetylene Flame over All Possible Gas Ratios.

The oxyacetylene flame as used for welding purpose requires a slightly greater volume of oxygen than acetylene. Since acetylene requires $2^1/_2$ volumes of oxygen for its complete combustion, the balance of the oxygen must be obtained from the atmosphere. This oxygen obtained from the atmosphere entrains with it four volumes of nitrogen that must be raised to the flame temperature and the latter, on account of its chemical inactivity, acts to cool the outer portion of the flame.

The thermal efficiency of welding quite conceivably could be greatly increased if a more efficient flame were possible and the acetylene industry would be greatly benefited by a knowledge of the effect on the flame temperature and chemical composition of varying the oxygen to acetylene ratio from the lowest possible to the maximum theoretical amount. It is possible that by mathematical treatment the flame temperatures with these various gas ratios could be predicted, and this problem is suggested as a line of research.

13. Temperature of the Oxyacetylene Flame for the Same Gas Ratios Mentioned in No. 12.

This problem is suggested for laboratory experiments in order to act as a check on the calculations obtained under Problem No. 13. The purpose in carrying out these problems in a theoretical and also in an experimental fashion is to give a clearer insight into the behavior of the oxyacetylene flame and to help reconcile differences that will undoubtedly arise between the experimental and theoretical results. By proper consideration and analytical treatment of the results in these two problems there would be provided valuable information not now available.

14. Economy of Heat Delivery from an Oxyacetylene Flame into a Steel Plate.

Presumably the heat transfer from the welding flame to a metallic surface is largely by radiation and conduction. Because of this, the total heat delivered into a plate during a welding operation is a relatively small percentage of the total flame energy and this inefficiency might be considered somewhat of a neconomic waste. If experiments could be initiated which would show definitely a means for substantial improvement, the whole industry would be very greatly benefited.

Generally speaking, the rate of heat delivery into a plate at room temperature is quite high but, as the temperature of the plate increases, the efficiency of heat transfer decreases as the temperature gradient between the plate and the flame decreases. It is, then, at the higher range of temperature, namely, 1200 to 1300° C., that the greatest inefficiency exists. The experiments, then, would naturally lead to a measure of heat input at high temperatures and with a wide range of gas ratios.

15. Spectroscope Examination of the Oxyacetylene Flame.

When acetylene is oxidized in the oxyacetylene flame, the reaction probably occurs in stages. The first stage may be the formation of carbon monoxide and incandescent particles of carbon, with possibly a very small quantity of carbon dioxide. These products of combustion are probably generated around the boundary of the inner cone. These gas reactions in the flame are of the reversible type and they can be carried to complete oxidation only after their temperature has been lowered by radiation and expansion such as occur in the outer flame envelope.

Hitherto, there has been no really conclusive data to indicate the nature of these reactions or their relative importance at the different stages. Substantial information on these points might be obtained by an exploratory study of the different regions in the welding flame with the aid of the spectroscope. The experiments should be carried out on the standard oxyacetylene flame as it is now used industrially, and also on flames having a wide variation of gas ratios. (See Problems (12) and (13).)

The information obtained in this proposed research might be used in conjunction with the researches mentioned under No. 13 and No. 14 to build up knowledge for increasing the thermal efficiency of the oxyacetylene flame.

16. Particle size distribution in an arc. The mechanics of metal transfer in an arc has not been fully investigated, and such information, if presented for coated electrodes of greatly differing arc characteristics may point the way for further improvements.

Group D—Problems Involving Welding Procedure

GENERAL NOTE: Apart from proprietary methods there is much to be done on both gas and arc welding, such as the effect of layer welding, of fore and backhand welding for gas, as well as up and down welding vertically by the arc. In gas welding non-ferrous alloys, excess oxygen and also excess acetylene should be tried. A considerable program could be worked out and the reports in some cases would require metallographic work as well as physical tests.

Many opinions exist in regard to different methods and much fragmentary information is available but it requires being placed upon a completely statistical basis.

1. Effect of Method of Making Gas and Arc Welds on Ductility. (One problem is the investigation of thick *vs.* thin layer: parallel *vs.* weaving of beads. This problem should probably be confined to flux coated electrodes.)

2. Effect of Peening on Quality of Welds.

The chief value of a study of this problem seems to be that some standard method of peening might be established. The question is usually, "How much peening to do, how to do it and what the effect should be." Too much peening can easily be more serious than no peening at all. Just where the limit is for best results is not known.

Peening has been used quite extensively in the electric arc welding industry to improve the quality of the deposited metal. Apparently it has the effect of relieving strain and giving a more reliable joint. There is some statistical information available in the trade journals and institutional records on the effect of this treatment, but it would be worth while to collect this information with the idea of presenting a comprehensive report which would cover the field more fully.

It is believed that the study should be carried out on welded plates of various thicknesses and of different materials. Also various methods of making the welds and varying amounts of peening at different stages of the welding operation should be used. The investigator should devise some strain gage method for determining the amount of benefit obtained from peening, and possibly some reliance should be placed upon the standard physical tests.

In addition to mechanical tests, micrographs should be taken to make a comparative study of welds with and without peening and with peening under different conditions and to different extents.

Mr. W. Spraragen states that the matter of peening of welds has been under discussion for many years. Some look upon it favorably and others do not. The matter received favorable consideration in connection with the relief of residual stresses in welds, particularly in the welding of heavy parts. Each layer is peened carefully and when properly done has apparently produced good results. Others feel that peening of welds if improperly done might actually do harm in starting initial cracks. They state that there are so many variables involved in peening, such as temperature, weight of hammer, type of hammer, frequency and size of blows, etc. Literature indicates that peening has been found very useful in preventing locked-up stresses and distortions in cast iron welding, manganese steel welding, the welding of heavy sections and pressure vessel welding referred to above.

The subject is closely related with residual stresses which is a complicated problem in itself. The effect upon peening of welds with different layers and different thicknesses of material as well as with covered and bare wire and by gas welding should be studied.

Whatever peening is done should be done in such a way that the exact conditions can be duplicated. Perhaps an air hammer with a definite air pressure might be utilized. Some tests would have to be made to determine whether the blows delivered from such a device were fairly uniform.

Mr. H. M. Hobart: "As one of several ways for releasing locked-up stresses and for improving in general the quality of the metal, peening should be considered. It should be applied (preferably with a pneumatic hammer) right after the weld has been completed and while the metal is still very hot. This has long been known to be a valuable method. But, while it has often been urged that a scientific technique should be developed by careful research tests at various temperatures and with various kinds and amounts of peening (such as the severity and periodicity of the blows), it does not appear that this has yet been done in an adequate manner, studying the quality and the relative freedom from internally stressed conditions after different peening techniques have been employed. The appropriate temperature conditions should be determined as well as the location of the application of the peening blows. In multiple-layer welding, should the peening process follow each deposit? Peening may lead to better welding of high-carbon steel or of non-ferrous metals or their alloys."

3. Effect of Stress Relief on Locked-up Stresses in Welded Specimens.

The highest grade of welded construction which is approved by the new boiler code of the A. S. M. E. requires that all welded vessels be annealed, regardless of their size before placing in service. The treatment requires raising to a temperature of 1100 or 1200° F. Some investigative work has been carried out along this line to determine the effect of the annealing treatment and some good results have been presented in the welding trade magazines as well as the Welding Journal.

The principle which is generally used is to make a

series of careful strain gage measurements before and after annealing, these being located in such a fashion as to reveal the effect of the treatment. With a proper regard for elastic and plastic deformation, an accurate measure of the residual stresses is obtained.

This work should be carried out on welds made by different processes and on various types of metal, as well as heating to different temperatures.

This problem would involve, essentially, heat treatment as well as strain gage measurements, and probably a few tensile and impact tests.

Effect of preheating and slow cooling on reduction of residual stresses in ferrous and non-ferrous castings repaired by welding would be useful information.

Aging value under normal atmospheric temperatures on reduction of residual stresses and quantitative change in the physical properties of the welded joint.

4. Temperature and Technique for Strain Annealing of Various Types of Welds.

5. Speed of Welding and relation of Amount of Current and Voltage.

NOTE: A record of the power consumption at the arc with these tests would provide definite information along a direction in which very uncertain information now exists.

6. Comparative Merits of Various Types of Welded Joints in Minimizing Strain.

7. Proper Welding Procedure to Obtain Satisfactory Welds in Hydrogen Atmosphere.

The experimental work on this problem need not involve the actual making and testing of welds since the chief concern is the amount of metal discharged from the tip of the electrode. In order to avoid the inaccuracies of hand welding, it would be desirable and almost necessary to do the work under automatically controlled conditions.

A careful study should be made of the amount of electrode melted off with varying arc voltage from the lowest to the highest practicable, and also with the lowest and highest current densities practicable for any size of electrode. Different combinations of these conditions should also be tried and a complete set of data be taken, including time, amount of material melted off and amount of material deposited.

These experiments should be carried out first of all on one standard composition and then repeated with varying compositions, in order to determine the influence of different elements in the electrode. In these experiments there has been assumed the use of a bare electrode but a similar set of data should be obtained for the covered type.

The objects of these experiments would be to help decide the nature of metal transference across the arc, to determine if there is an optimum current for the different electrode diameters, the influence of electrode composition on deposition efficiency, as well as a number of other features which the experimenter would realize as he carried on the work.

Similar experiments might be conducted with atomic hydrogen and other special forms of electric welding. Also A.C. and D.C. sources of power should be used to complete a well-rounded set of data.

8. Effect of Size, Number of Layers, Length and Shape of Fillet Welds on Their Strength.

9. The Effect of Annealing (above and below the critical range) on the Physical Properties and Machinability of Welds. (Particular attention should be given to alloy and high-carbon steel.)

10. Effect of Speed (fast or slow welding) on Quality of Weld and Effect on Adjacent Material when Resistance Welding Different Steels and Non-Ferrous Metals and Alloys.

11. Study of Different Methods of Resistance Welding and the Effect of Such Welding on the Material Welded. (This should be done on different steels and non-ferrous metals and alloys.)

12. Effect on Resistance Welding of Coatings Such as Dirt, Oxide and Different Plating Such as Zinc, Cadmium, Lead, Tin, Chromium and Others When Applied to Steels and Non-Ferrous Metals and Alloys.

13. Penetration: Advantages and Disadvantages of Deep Penetration.

NOTE: This problem might be stated, "Is deep penetration necessary?"

It is of advantage to the industry to show that penetration need be no greater than necessary to make molecular union of the weld metal and the base material.

The experimenter should preferably be a welder in order that he could alternately weld and then study the effects of varying penetration on his welds. There are few experimenters who are expert enough in welding to make a proper job of this. Such a problem would have great usefulness and should be carried out in gas and arc welding.

It is probably safe to say that most practical welders desire to work with a set of conditions which will give deep penetration into the base metal when carrying out a weld. The origin of this conception undoubtedly dates to the earlier development period of welding and the practice has undoubtedly become widely accepted because deep penetration would somewhat naturally become associated with more complete fusion at least in the mind of the average welder. Deep penenetration would have the psychological effect of giving him more assurance that complete union between the applied metal and the base metal had been effected.

14. Capacity to produce satisfactory resistance welds in different individual and total thicknesses of material, using a given setting of the machine.

15. Proximity Effect—Resistance Welding. What spacing of spot welds will insure sound results in different individual and total thicknesses of material with a given setting of the machine.

16. Investigate the Weldability of Different Grades and Thicknesses of Copper by Using Different Filler Rods and Welding Processes. Work Up a Welding Technique for Each Suitable System of Variables and Compare the Different Processes by Making Physical Tests on the Welds.

17. Possibilities of Welding Alloy Steels in Various Gases.

18. The Repair of Manganese Steel Railroad Castings.

Group E—Structural Studies

1. Study of the Action of and the Stresses in Welded Connections of Beams to Beams.

This should be a combination of experiments and mathematical analyses to ascertain the action of welded connections which join steel beams in building construction and to deduce formulas for use in designing such joints.

2. Resistance of Welded Joints to Variable Loads. It is suggested that for this item methods of testing can be devised which can be carried out easily. It is also necessary to classify the various types of loading, producing variable stresses in welded joints. These variable stresses occur in bridges, crane runways, ships and possibly other important structures.

3. Photoelastic Studies of Stresses in Welded Joints.

Because of the rapidly widening application of welding to all forms of construction, there has arisen a need for

reliable analytical methods for studying the stresses set up in welded joints.

There has come to the forefront in recent years a photoelastic method for treating this subject. Generally speaking, it consists of studying, by means of polarized light, the stresses set up in xylonite models. This method has proved its usefulness by explaining apparent irregularities in stress conditions.

If any laboratory should desire to take up this method of stress analysis, the American Bureau of Welding will be glad to submit designs of various types of joints that lend themselves to this method of analysis.

In photoelastic work it is suggested that three types of specimens that form part of the program of the Structural Steel Welding Committee would produce interesting results. These are as follows:

I. Butt joints with intermittent welds, Series 3800, 3900 or 4000.

II. Diagonal butt joints with intermittent welds, Series 4400 to 5200.

III. Single tee joints with fillet welds in parallel shear, Series 5700. This type of joint can be tested by placing it first in a horizontal position and then in a vertical position so as to measure the stresses in both planes.

A thickness of $^3/_{16}$ in. or $^1/_4$ in. has been found to give satisfactory results.

4. Experimental Check on Theoretical Methods of Computing Stresses in Welded Joints.

5. Girder Design. Continuous *vs.* intermittent welds for connecting flanges to web and stiffeners to web. It is the belief of some that a large amount of excess welding does harm and does not add to the strength of the girder.

Group F—Problems Involving Chemistry

1. Relations between Chemical Composition, Mechanical Properties and Weldability of Steel.

A special problem in this field is the weldability of "rimmed" steel by the various processes.

2. Viscosity Melting Point and Surface Tension of Coatings (Slags) for Electrodes.

3. Corrosion of Welds.

Group G—Psychological

1. A Psychological Study of the Effect of Continued Welding on the Operator, with Particular Reference to the Effect of Weariness on the Quality of Welding.

2. Physiological effect of arc rays, and fumes from electrodes, zinc, paint and base metal on welding operator.

Library Research

Arrangements are at present being made for Library Research on various important welding subjects. It is believed that, without in any way reflecting upon the value of Laboratory Research, a given outlay on Library Research may, in many fields of investigation, advance our knowledge at least as much as an equal expenditure on Laboratory Research. Possibly men of different temperament and training will be found most effective in each of these two respective kinds of research activity and the kinds of problems best solved by Library Research will be different from those which should be solved by Laboratory Research.

But the present is an excellent occasion for a demonstration of the value of the heretofore terribly neglected Library Research method, since many of the ablest addicts of Laboratory Research, while at present (owing to the world economic dilemma) debarred from its practice, can transfer their activities to well-equipped Libraries and salvage submerged facts and data and build upon this material, important truths, conclusions and discoveries.

This may, after the return of more normal economic conditions, lead to a much more intensive use of Libraries and there will be, in Laboratory Research, less (unintentional) waste in repeating, at great expense, already well-made experiments and in learning, by expensive tests, truths which would dawn upon the Library Researcher as the result of his intelligent study of published data concerning the underlying facts.

Conclusion

The Committee will greatly appreciate cooperation from those interested in these subjects in the form of additional suggestions, opinions and comments to follow the particular titles in the list below, to which they respectively relate. These communications should be sent to Mr. W. Spraragen, the Committee's Secretary, at 29 West 39th Street, New York N. Y.

Alphabetical List of Researchers, Their Affiliations and Their Subjects. (As Revised Aug. 1935)

	Research Being Conducted by	Affiliation	Name of Chairman of Regional Section	Subject of Research
1	Prof. C. A. Adams and Dr. A. Sauveur	Harvard University	J. H. Zimmerman	Influence of the Welding Heat on the Structure of the Adjacent Metal.
2	Prof. Edward Bennett	University of Wisconsin	J. Muller	Studies Relating to the Selective Heating of Large Conducting Bodies in Strips by Utilizing the "Proximity Effect" to Control the Distribution of Heating Currents of the Audio Frequency Range.
3	Prof. A. H. Beyer	Columbia University, Dept. of Civil Engineering	J. M. Keir	Photoelastic Studies of Lap Welded Joints.
4	A. G. Bissell	Seattle, Washington	A. G. Bissell	
5	Prof. H. M. Boylston	Case School of App. Science, Dept. of Metallurgy	C. H. Jennings	(*a*) Metallurgical Investigations on Welds. (*b*) Factors Influencing the Welding Quality of Steel.
6	Hemingway R. Bullock	Mass. Inst. of Technology	J. H. Zimmerman	Changes in Microstructure at Stress Relieving Temperatures.
7	Prof. F. Creedy	University of British Columbia	A. G. Bissell	(*a*) Characteristics of the Copper Arc, Between Revolving Electrodes. (*b*) Physics of the Arc. (*c*) Characteristics Required for Steady Welding. (*d*) Characteristics of Welding Apparatus (i.e., in Arc Welding).

Alphabetical List of Researchers, Their Affiliations and Their Subjects. (As Revised Aug. 1935) (Continued)

	Research Being Conducted by	Affiliation	Name of Chairman of Regional Section	Subject of Research
8	J. J. Crowe	Air Reduction Sales Co.	J. M. Keir	Cutting.
9	Prof. R. P. Davis	West Virginia University		Welded Structural Members.
10	Prof. A. V. de Forest	Mass. Inst. Technology, Mechanical Eng'g. Dept.	J. H. Zimmerman	Vibration Studies of Welded Structures.
11	Prof. Gilbert Doan	Lehigh University, Dept. of Physical Metallurgy		(*a*) A Study of Metal Transfer During Arc Welding. (*b*) A Study of the Basic Nature of the Arc Discharge Under Conditions of High Purity. (*c*) The Properties of Weld Metal Made with Pure Iron in Argon and Other Atmospheres. (*d*) The Use of Gamma Rays for Weld Examination. (*e*) Acceleration of Rate of Welding by Additions to the Welding Wire.
12	A. S. Douglass	Detroit Edison Co.		Library Research on Temporary and Permanent Weld Stresses.
13	Prof. D. J. Demorest	Ohio State University	C. H. Jennings	Non-Destructive Tests for Welds by Magnetic Methods, X-Ray and Radium Ray.
14	Prof. S. L. Goodale	University of Pittsburgh, Dept. of Metallurgy	C. H. Jennings	(*a*) Annealing of Welded Joints. (*b*) Strain Annealing of Medium Carbon Steel (.25 to .30%).
15	Prof. A. Haertlein	Harvard University	J. H. Zimmerman	Analysis of Structural Welding Problems.
16	Prof. P. R. Hall	Penn. State College, Dept. of Industrial Engineering	C. H. Jennings	Welding of Cast Iron.
17	O. M. Harrelson	Georgia School of Technology, Mechanical Eng'g. Dept.		The Effect of Controlling Welding Procedure and Peening on the Physical Properties and Transition Constituents of the Material.
18	Prof. W. A. Harvey	J. A. Roeblings Sons Co.		Corrosion Fatigue Testing.
19	Prof. Otto Henry	Brooklyn Polytechnic, Mechanical Engineering Dept.	J. M. Keir	Effect of Low Temperature on the Static and Dynamic Tensile Strength of Welded Joints in Some Ferrous and Nonferrous Metals.
20	Prof. W. F. Hess	Rensselaer Polytechnic	A. Vogel	(*a*) Magnetic Characteristics of Deposited Metal. (*b*) Carbon Arc Welding.
21	Prof. N. S. Hibshman	Lehigh University		Under Water Welding.
22	Prof. P. Hodge	Stevens Institute of Technology, Dept. of Physics	J. M. Keir	Characteristics of the Thermit Weld.
23	Prof. S. C. Hollister	Cornell University	A. Vogel	Locked-Up Stresses in Welds.
24	Prof. T. P. Hughes and H. R. Chhabra Prof. T. P. Hughes and E. Nelson	University of Minnesota, Dept. of Mech. Eng'g.	J. Muller	Relation of Current and Voltage to Speed of Welding. Ductility Values as Obtained by the Tensile and Cold Bend Tests.
25	Prof. R. E. Jamieson	Prof. of Civil Engineering, McGill University, Montreal	A. Vogel	Initial Stresses Caused by Welding.
26	Mr. C. H. Jennings	Westinghouse Electric & Mfg. Co., Pittsburgh	C. H. Jennings	Strength and Design of Welded Joints.
27	Prof. C. D. Jensen	Lehigh University, Dept. of Civil Engineering		Investigation of Welded Brackets. Under-Water Welding.
28	J. M. Keir	Union Carbide & Carbon Research Laboratory	J. M. Keir	
29	Prof. W. B. Kouwenhoven	Johns Hopkins University		(*a*) Flux Penetration Tests. (*b*) Non-Destructive Tests for Welds.
30	Prof. W. J. Krefeld	Columbia University, Dept. of Civil Engineering	J. M. Keir	Initial Strains and Residual Stresses Resulting from the Heating Incident to the Welding Operation.
31	Prof. P. G. Laurson	Yale University, Dept. of Eng. Mechanics	J. M. Keir	
32	Prof. T. R. Lawson	Rensselaer Polytechnic Institute Head of Dept. of Civil Engineering	A. Vogel	(*a*) Quantitative Studies of the Stresses Caused by Welding Operations. (*b*) Photoelastic Studies of Stresses in Riveted and in Welded Joints. (*c*) Impact Stresses in Welded Joints.

Alphabetical List of Researchers, Their Affiliations and Their Subjects. (As Revised Aug. 1935) (Continued)

Research Being Conducted by		Affiliation	Name of Chairman of Regional Section	Subject of Research
33	Dr. H. H. Lester	Watertown Arsenal	J. H. Zimmerman	X-Ray Specifications for Castings and Welded Structures.
34	Prof. Inge Lyse and D. M. Stewart	Fritz Engineering Lab., Lehigh University		(*a*) Photoelastic Studies of Bending in Welded Joints. (*b*) Rigidity of Welded Structural Connection.
35	Prof. P. M. Lincoln	Cornell University College of Engineering	A. Vogel	
36	F. S. Mapes and F. Howenstein	Schenectady Works Laboratory, General Electric Co.	A. Vogel	Bend Testing Methods.
37	Prof. H. J. Masson	Professor of Chemical Engineering, New York Univ.	J. M. Keir	Corrosion Fatigue Tests of Welded Joints.
38	Prof. C. Moser	Stanford University, Civil Engineering Dept.	N. F. Ward	
39	Jules Muller	C. H. Hollup Corporation, Chicago, Illinois	J. Muller	
40	Dr. D. W. Murphy	University of Michigan, Dept of Eng'g. Research		Determination of Oxygen and Nitrogen Content.
41	Dean J. A. Needy	Ohio Northern University, College of Engineering	C. H. Jennings	Problems in the Welding of Cast Iron.
42	Prof. J. T. Norton	Mass. Inst. of Technology, Dept. of Mining and Metallurgy	J. H. Zimmerman	(*a*) Radiographic Technique of Examining Welds. (*b*) X-Ray Diffraction Method for Investigating Stresses in Welds. (*c*) X-Ray Studies of Age-Hardening.
43	Prof. O. D. Rickly	Ohio State University, Dept. of Industrial Engineering	C. H. Jennings	Study of Residual Stresses in Welded Joints Shear and Impact Tests of Welds.
44	Dr. M. F. Sayre	Union College, Dept. of Civil Engineering	A. Vogel	(*a*) Development of Methods of Testing Welds. (*b*) Relation of Ductility to Other Physical Properties.
45	Prof. G. S. Schaller	University of Washington, Dept. of Mech. Eng'r.	A G. Bissell	(*a*) Development of an Arc with a Gaseous Atmosphere. (*b*) Oxyacetylene Welding of Cast Iron.
46	Norman G. Schreiner	Fritz Engineering Laboratory, Lehigh University		(*a*) The Investigation of Welded Seat Angle Connection. (*b*) The Strength of Welds in Bending. (*c*) The Investigation of Fillet Welds Under Combined Bending and Shearing Forces.
47	Prof. C. T. Schwarze	Prof. of Civil Engineering, New York University	J. M. Keir	(*a*) Use of Bend Test for Measurement of Ductility. (*b*) Investigations of Impact Testing Methods. (*c*) Photoelastic Studies of the Stresses in Welding Joints.
48	Prof. R. R. Seeber and A. P. Young	Michigan College of Mining & Technology, Dept. of Mech. Eng.		(*a*) Copper Welding. (*b*) Method of Testing Welds.
49	A. Solakian	Columbia University	J. M. Keir	
50	W. Spraragen	Am. Bureau of Welding	J. M. Keir	Resistance of Welded Joints to Impact.
51	Prof. J. G. Tarboux	University of Tennessee		Magnetic Field Intensities Surrounding Arcs.
52	Prof. L. Thomassen	University of Michigan, Dept. of Chemical Eng'g.	A. S. Douglass	(*a*) Changes in the Diffraction Pattern on Straining and Annealing Metals and Alloys. (*b*) Localization of Defects in Welds by Means of X-Ray Stereoscopic Pictures.
53	Prof. G. E. Thornton	State College of Washington, Dept. of Mechanical Eng'g.	A. G. Bissell	Fatigue Tests.
54	A. Vogel	Schenectady Works, General Electric Co.	A. Vogel	(*a*) Investigations of Forms of Impact Tests. (*b*) Investigations of Forms of Shear Tests.
55	J. P. Walsted	Bethlehem Shipbuilding Corp., Quincy, Mass.	J. H. Zimmerman	
56	Prof. N. F. Ward	University of California, Dept. of Mech. Eng'g.	N. F. Ward	(*a*) Creep Tests of Welds. (*b*) Some Controlling Elements for Resistance Welding of Thin Gauge Metals. (*c*) Study of Resistance Drop During Resistance Welding of Thin-Gauge Metals of Low Resistivity Especially in Relation to Spacing of Welds for Uniform Strength.

57	W. L. Warner	War Department, Watertown Arsenal	J. H. Zimmerman	(*a*) Arc Welding of High Tensile Steel Alloys. (*b*) Nitrogen in Welds.
58	Prof. A. E. White, Dr. C. L. Clark and R. Schneidewind.	University of Michigan	A. S. Douglass	(*a*) Creep of Metals and Welded Structures at High Temperatures. (*b*) Resistance to Oxidation, Embrittlement and Fatigue.
59	Prof. W. M. Wilson	University of Illinois, Dept. of Civil Eng'g.	Jules Muller	Moment Resisting Connections for the Steel Frames of Buildings.
60	Dr. M. Yatsevitch	Watertown Arsenal	J. H. Zimmerman	Coefficient of Expansion of Weld Metal.
61	Prof. J. H. Zimmerman	Mass. Inst. of Technology, Dept. of Mech. Eng'g.	J. H. Zimmerman	Fatigue Tests of Full Size Specimens.

TABULATED GROUPING OF RESEARCHERS AND RESEARCHES

	DESTRUCTIVE TESTS ON WELDS AND WELDED JOINTS.									PROPERTIES.		METALLURGICAL INVESTIGATIONS.						METALLOGRAPH		TESTS ON JOINTS OR ON ENTIRE STRUCTURE.									NON-DESTRUCTIVE TESTS.								OTHER FIELDS OF RESEARCH ACTIVITIES.															
	TENSION.	COMPRESSION.	BENDING	SHEAR	TORSION	IMPACT	FATIGUE	SPECIFIC GRAVITY	CREEP	DUCTILITY	HARDNESS	HEAT EFFECT	COOLING SHRINKAGE ON STRUCTURE OF METAL	HEAT TREATMENT	CHEMICAL TESTS	AGING (DECAY)	METALLURGICAL GENERAL	CORROSION	OPTICAL INVESTIGATIONS.	METALLOGRAPHIC GEN.	TESTS ON STRUCTURES.	HYDROSTATIC TESTS.	VIBRATION TESTS.	PHOTOELASTIC	STRESS DISTRIBUTION	ELEVATED TEMPERATURES.	LOWER TEMPERATURES.	TESTS IN GENERAL	SPECIFICATIONS	TESTS ON ALLOYS	VISUAL EXAMINATION	X-RAY	GAMMA RAY	MAGNETIC.	ELECTRICAL.	ACOUSTIC.	LEAKAGE.	INSPECTION DURING WELDING.	NON DESTRUCTIVE GENERAL	METAL TRANSFER	FLUXES.	ATMOSPHERES OTHER THAN AIR	COVERING OF ELECTRODE	MAGNETIC CHARACTERISTICS OF STEELS.	CARBON ARC WELDING.	WELDING UNDER WATER	FIRE HEATING WITH HIGH FREQUENCY.	CHARACTERISTICS OF THE WELDING MACHINE	RESISTANCE WELDING	THERMIT WELDING.	A.C. ARC WELDING.	CUTTING CAST IRON.
PROF. C.A. ADAMS; DR. A. SANVEUR.												X																																							
PROF. EDWARD BENNETT.																																																X				
PROF. A.H. BEYER.																								X	X																											
A.G. BISSELL.																																																			
PROF. H.M. BOYLSTON.																	X													X																					
HEMINGWAY R. BULLOCK.														X					X																																	
PROF. F. CREEDY.																																											X						X		
J.J. CROWE.																																																			X
PROF. R.P. DAVIS.																					X																															
PROF. A.V. DE FOREST.																						X																														
PROF. GILBERT DOAN.																																		X									X		X	X						
A.S. DOUGLASS.												X																																								
PROF. D.J. DEMOREST.																																	X	X	X																	
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PROF. A. HAERTLEIN.																					X																														
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W.J. Slate AUG. 7, 1935.

APPENDIX A

CONTENTS

Progress in Welding Technique in the Second Half Year 1934*

1. Influence of the Base Metal
2. Welding Processes
3. Test Methods
4. Characteristics of the Weld
5. Behavior in Service

By WILHELM LOHMANN and WALTER SCHNEIDER

1. Influence of the Base Metal

TO investigate the relationship between the chemical composition of the base metal, the filler rod and the weld seam, E. Haardt[1] has made experiments with steels alloyed respectively with silicon, manganese nickel, chromium and copper. In every case except copper, these alloys had 3.85% of the alloying constituent. But in the case of the copper alloy, the percentage of copper was, for weld technique reasons, chosen lower and amounted to 1.38%. In all cases, the welds were made both with bare and with covered non-alloyed electrodes. Haardt determined the amount of the alloying elements which were absorbed by the weld seam, which he explains as occurring through diffusion phenomena. It was found that the amount of silicon absorbed in the weld seam was relatively low; with bare electrodes, however, the silicon content was considerably higher than with coated electrodes. Already in the transition zone, a decrease of the silicon content in the base metal was observed so that a diffusion in the plastic condition is to be assumed. This, however, in the case of the bare electrode, was less pronounced than with the covered. The same relations showed themselves fundamentally with manganese alloyed steels. However, a slight dependence of the diffusion on the current strength was found, which was explained by Haardt as due to the scorification of a part of the constituents of the alloy. The investigation of the chrome-alloyed steel was found to be very difficult due to pore and slag formations. Also, in this case, the author's results show that the oxide and slag layers were disadvantageous for the diffusion in the weld seam. The highest diffusion values were found with a nickel alloyed steel and, in this case, in contrast with the silicon alloyed steel, the nickel content absorbed into the weld seam during welding was greater with covered electrodes than with bare electrodes. On the average, there was found in the weld seam independently of the current strength, 25 to 50% of the original nickel content. With the copper alloyed steel, a very great diffusion was found; in the outermost layers of the weld seam, some 50% of the copper content of the base metal was found. In this case also, the diffusion was higher with the covered electrodes than with the bare electrodes. With two-layer welding, the absorption of alloy elements was relatively higher than with one-layer welding. However, these values relate, above all, to the alloy content in the first weld layer. Whether these differences are conditioned or not by the less share of alloy constituents in the weld seam, cannot be determined without further investigation.

In addition to the above tests, Haardt investigated, with bare and covered electrodes, the absorption of nitrogen as a function of the constitution of the alloy in the base metal. Also, here it was found that even in the transition zone there was a slight enrichment with nitrogen and that it was not until the weld deposit was reached that a considerable absorption of nitrogen occurred, which, with bare electrodes, naturally was greater than with covered. It was, however, surprising that with both kinds of electrodes, the absorption of nitrogen with silicon alloys for the base metal was considerably less than with the other alloyed steels.

With regard to the tests, the following observation is fundamental: In addition to the diffusion of the alloy constituents investigated by Haardt, there takes place also a pure mixing because, owing to the penetration, a certain part of the base metal becomes melted and mixed with the electrode material. Only as far as the transition zone comes into consideration can the phenomena by diffusion be explained. Furthermore, Haardt, in his tests, did not state whether the alloy constituents contained in the weld seam were present in metallic form. It is to be assumed that, especially with metal alloyed with silicon, a part of the silicon was present in the form of silicic acid. Among other reasons, the smaller silicon content in the weld seam in the tests with the covered electrodes indicates this. Owing to the slag, there is rendered possible a rather great absorption of silicic acid. The same should apply for manganese and chromium alloyed steels, while, as is well known, nickel and also copper are less inclined to oxide formation.

J. Müller[2] reports with regard to faults in welds with steels of great strength, which, in particular, are of significance for aircraft construction. These faults manifest themselves particularly immediately adjacent to the weld seam and may be recognized by the formation of an iron oxide skin and by tempering colors in the fracture of the weld joint. These fault appearances are doubtless occasioned by stresses and Müller investigated their relation to material faults, faults of the added material and faults during the welding process, and he first paid his attention to the composition of the base metal. For this purpose, a suitable holding device was developed, in which plates of definite widths were mounted, welded and left until they were completely cooled. Müller

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* A translation of an article by Wilhelm Lohmann and Walter Schneider, entitled "Fortschritte in der Schweisstechnik im Zweiten Halbjahr 1934." This article was published in the May 2, 1935, pp. 495 to 498,and May 9, 1935, pp. 521 and 522, issues of *Stahl und Eisen* and the translation is reprinted in America with their permission. Reference should also be made to an article by Wilhelm Lohmann with a similar title but covering the FIRST half year 1934. This article appeared at pp. 1212 to 1216 of the Nov. 22, 1934, issue of *Stahl und Eisen*. At pp. 809 to 811 and pp.832 and 833 of the August 2nd and 9th, 1934 issues of *Stahl und Eisen*, there was published an article by Ernst Hermann Schulz and Wilhelm Lohmann which similarly covered the SECOND half year 1933.
(Translation by H. M. Hobart.)

determined that the tendency to crack in welds occurred most of all when, with a rather high carbon content in the base metal, there was an insufficient degree of purity of phosphorus and sulphur as well as a pronounced refining zone. Steels subject to weld cracks showed, on microscopic examination, peculiar ferrite spots within coarse perlite grains in the transition zone. The corresponding occurrences could not be observed with special steels. Müller developed a diagram from which, with given carbon content, there can be learned the influence of the total content in phosphorus and sulphur on the tendency toward weld cracks. In metals for aircraft construction, it is also required that they shall be readily machinable adjacent to the welded seam; consequently, no very great increases in hardness ought to occur. For testing the tendency to hardness, Müller welded onto a piece of steel tubing, a strip of plate of 30 x 20 mm.[2] of the metal to be tested. With a flat-nosed plier, he held this plate at a distance from the weld seam of double the plate thickness and bent it back and forth till the fracture occurred. According to experiments so far made, the chrome molybdenum steels could be bent without fracture by at least 90° right at the weld seam. A dependence between the tendency to crack in welds and the hardness of the transition zone was not determined.

For certain applications, pressure vessels are required which, at low temperatures, are exposed to various stresses, of which some are impact stresses. Consequently, for such pressure vessels, the notch impact toughness at low temperatures is of especial importance. In most cases, the usual process of making alloyed steels so that they will resist impact stresses at low temperatures is based on a heat treatment at rather high temperatures. For large pressure vessels, such a treatment, however, does not come into consideration, but merely an annealing above or below the transition point. Very notable investigations regarding the notch toughness of welded joints at low temperatures were carried through by R. K. Hopkins[3] with various steels whereby especially a heat treatment of 2, 6, 12 and 36 hours at some 650° C. was employed. There were investigated an unalloyed carbon steel with approximately 0.1% carbon, a molybdenum steel with 0.25% molybdenum, a silicon steel with 0.22% carbon and 0.21% silicon, 2 nickel steels with 2.1 and 3.5% nickel, a vanadium steel with approximately 0.2% vanadium and a manganese-vanadium steel of unknown composition. The tests were made at +20°, −30°, −45° and −60° C. The welding was done with wires, which gave, in the weld seam, a composition similar to that of the base metal. With the nickel steels, however, it was purposely attempted to obtain a nickel content in the weld seam of 1.2 and 1.7%. The report does not contain more precise data with regard to the kind of electrodes. According to the report, the period of heat treatment at 650° C. exerted an influence only with the nickel steels. With a content of 3.5% nickel, there occurred with increasing duration of annealing, an increase of the strength. The authors explain this fact by the lower transition point of the nickel steel and the thereby occasioned carbide formation with longer duration of annealing. It is questionable whether this explanation is correct.

According to Hopkins' results, the non-alloyed steels as well as the molybdenum and silicon alloyed steels are not suitable for pressure vessels which must withstand impact stresses at low temperatures. On the other hand, Hopkins believes that with further investigations, molybdenum steels, with a definite treatment, may lead to useful results. The best results were, at any rate, obtained with welded vanadium alloys and, above all, with nickel alloyed steels. Of the steels with 2.1 and 3.5% nickel, the material with the smaller nickel content was to be preferred. In the weld seam itself, molybdenum and vanadium alloyed welding wire behaved especially well so that the author attempted to weld the lightly alloyed nickel steel with such welding wires in order to still further improve the results. As a matter of fact, a considerable improvement of the impact properties of the weld joints could thereby be obtained, which, however, did not give such good characteristics as were obtained with welding wires corresponding to the base metal. For this lower notch toughness with the nickel steels, the author found no explanation. It might, however, be assumed that a greater nickel content in the weld seam reached it from the base metal and that thereby was caused the decrease in the notch toughness as compared with vanadium and molybdenum and alloyed materials. According to these tests, a nickel steel with some 0.25% carbon and approximately 2% nickel is suitable for low temperature. Furthermore, there were tested, according to the procedure established by Hopkins, manganese steels with 0.24% carbon, 0.03 to 0.37% silicon, as well as with 1.2, 1.5 and 2.1% manganese. The steels showed, however, not only in their non-treated, but also in the annealed as well as in the normalized condition, substantially less notch toughness values than the above-mentioned nickel steel.

In order to check the correctness of the test results, an experimental pressure vessel was welded using two different electrodes, employing for one half of the pressure vessel, steel just as it first came from the mill, and for the other half, steel which was given a normalizing anneal before being rolled to shape. The experiment showed that it is advantageous before welding to normalize the plate by annealing and to roll it warm. The notch toughness results confirmed again the usefulness of the above-mentioned welded nickel steels for low temperatures. As to further particulars of the investigation, reference must be made to the report itself.

2. Welding Processes

Based on earlier experiments in the welding of railroad rails, C. F. Keel[4] reports on rail joints which were gas-welded on sections of road on which trains were operating and without removal of the rail sleepers. The working process is nearly the same as that which has been formerly described.[5] Before welding, the sleepers were somewhat raised and the fish plates removed from the rail ends. The heads and feet of the rails—the web was not welded—were cut slantingly with a cutting burner, and then the rail foot was welded, and after that, the rail head. After completion of the welding, there took place a smoothing of the surface of the weld seam by suitable hammering. Furthermore, the welded joint was warmed at dull red heat for ten minutes. Care was taken that during cooling the rail should be able to shrink slowly without constraint, and after releasing the non-welded end, light jarring was imparted to the rail by blows on the end in the rail direction. The joint was then reinforced by bolted fish plates. The time for the making of a rail joint amounted to about one hour and a half. With sufficient intervals between the traffic on the section, such welding may be carried through without suspending the service. In these ways, 22 rail joints were welded. Switzerland has now 3 experimental sections in which the rails are provided with gas-welded joints, which have been in constant service for 12 months. No faults of any kind have yet been observed.

The question of the welding of rail joints has, in the case of gas welding, been thoroughly examined by experiments on a service scale, while as regards arc welding, there have heretofore been carried out only very few

experiments. For that reason, endurance tests which were carried through on electrically welded rail joints of various kinds are of significance.[6] The rail joints were prepared in four different manners. In all four cases, the weld head was welded with a V-seam. With the first method, a rectangular foot plate was located under the rail foot; in the second, a similar plate but with clamping cheeks; in the third, a trapezoidally-formed foot plate with clamping cheeks; and with the fourth method, there was chosen a pure butt joint without foot plate. Endurance tests which were carried out with a 40-ton Amsler pulsator, showed that with the first method, the Wöhler curve is very steep and bends down below the required impact load. The second and third methods led to more favorable behavior and, for the same stress as was used in testing the first method, permitted of a higher number of alternations of stress. But from the practical standpoint, they also cannot come into consideration for a welded joint subjected to repeated bending. The butt joint alone, in which both the rail head and the rail foot were welded, showed an endurance strength of approximately 14 kg./mm.^{2} corresponding to an alternating loading occurring in service of 10 kg./mm.^{2} Such a joint would, therefore, provide a safety factor of 1.4 against fracture with service loading. The cause of the failure of the weld joints which were provided at the rail joint with a fish plate under the foot of the rail, may have been ascribable chiefly to the unfavorable stress distribution in the rail foot and to the effect of the fillet seams, which, as is well known, occasion stress peaks.

A new process for building up welding (usually relating to depositing weld metal on worn parts) was developed by the Harnischfeger Corporation of Milwaukee.[7] In this process, a carbon arc was employed, which, with its soft flame, is claimed to be particularly suitable for building up welding on worn rail ends. The piece, of which a worn surface is to be built up, is first warmed by holding the positive pole at a distance of $^3/_4$ in. to $1^1/_4$ in. above it; then a fluxing material is added and not until there has been formed a glassy slag is the welding wire employed. The welding wire itself is said to be a steel similar to one with from 12 to 14% manganese; but the detailed composition is not stated. If the welded surface is hammered after the welding, there takes place an increase of the hardness from 235 up to 300 to 350 Brinell units. It is stated that if the job is carried out in the technically correct manner, there will be no necessity for grinding down the built-up place.

The development of the technique of welding has resulted in the introduction in steel constructions, of departures from the standard profiles previously employed for rolled sections. In various respects, the new profiles take advantage of the technique peculiar to welding. Among various changes, more favorable moments of inertia are provided which permit of decreasing the weight of steel required for a given strength in a fabricated structure. In the course of recent years, a series of beam designs have been developed in which their appropriateness for use in welded structures has been the dominating consideration. One of these in which a so-called "nose" profile is employed is of especial interest and is explained and discussed in recent articles [8,9,10] in technical journals.

P. A. Schmatz[11] reports on a variety of spot welding termed projection spot welding. The process is based upon providing raised places at the parts to be joined. These raised places are often already made in the pieces in presses at locations corresponding to the desired welds. The spot welds are made at these raised places. The process is receiving great attention and is widely used, especially in mass production. The application possibilities of the process are described by a number of examples.

In manufacturing the electrodes for spot welding machines, requirements are frequently made in addition to good electrical conductivity, which are dependent upon the kind of material to be welded. Above everything, attention must be given to providing in the electrodes high compression strength, a requirement which is, in general, not fulfilled by the known good conductors of electric current. J. J. Kelly[12] reports about electrodes for projection spot welding which consist of an alloy of copper and beryllium which, in addition to good conductivity, have high compression strength. The alloying proportions are not stated. Since the compression strength of the alloy is increased by heat treatment (regarding which, likewise, no further particulars are given), it is desirable, in order to avoid deformations, to first machine the alloy materials to the desired dimensions and to weld them together, and after this work is done, to heat-treat the product. For this heat treating of the weld, the carbon arc is recommended as being of all means the most appropriate.

The so-called light weight flasks come more and more into consideration in recent years for liquefied gases on account of the transportation costs and the handling of the flasks. In Germany, their manufacture by means of fusion welding is bound up with the proof of the reliability of the joints. A. Wiegand[13] describes the manufacture of light flasks for the transportation of liquefied gases like propane and butane which, at 25°, have vapor pressures of 8 and 1 atü,* respectively, and at 50°, of 15 and 3 atü, respectively. In the manufacture of these flasks, two spherical caps of 4.5 mm. plate thickness are stamped out while warm in a press and are provided with centering shoulders. These are joined by gas welding to the two ends of a seamless tube of 3 mm. plate thickness by means of 2 circular seams. As filler metal, there is employed a welding wire corresponding to the quality G V 2. The threaded parts for the opening are fitted from within, project through the wall and are secured by an external fillet weld. For the designation of the flask, a brass nameplate is soldered upon it. In bursting tests, the break occurred in the original material at a pressure which corresponded to a safety factor of 9 for propane at 50° C. It is hoped to effect a further decrease in cost by using tubes with a longitudinal welded seam instead of using seamless tubes. With higher pressures, however, the seamless tube will be preferable as it insures greater safety.

3. Test Methods

In the report about progress in welding technique in the first half year 1934,[14] the investigation published by G. Fiek and A. Matting entitled "The Suitability of the Folding Process for Testing Welded Joints,"[15] was critically discussed. Criticism in the form in which it appeared was not justifiable, for the reason that, as set forth in a memorandum which the authors of the paper addressed to these reporters, the tests were made about two years before the publication of the paper was undertaken and, consequently, at a time when the requirements as regards tensile strength of welded joints amounted to only 90% of the nominal strength. Consequently, the criticisms raised, especially as regards Electrode C, were not applicable. Furthermore, the authors explained that in the matter of the cost question, they had based their figures on plates which were not available to them. These facts were not mentioned in

* atü is abbreviation for pressure above atmosphere expressed in atmospheres of 1.43 lb. per sq. in. (1 kg. per sq. cm.).

the published abstract of the investigation. The present reporters subscribe fully to the conclusion stated in the publication referred to, namely, that:

"The folding test does not have scientific value and preference should be given to the simplest experimental method for testing the deformability of a welded joint. The folding test suffices, however, for a quick test of a workshop nature and yields sufficiently exact technical information regarding the characteristics of the welded seam as a joining element."

In the controversy about the question of the bend angle, the proposal has often been made to replace the bend angle, which is dependent upon a large number of influences, by the bend elongation in the folding test. F. Rötscher and J. Quadflieg[16] make a contribution to this question in which they compare the bend extension when different electrodes are employed for welding a given base metal and also with the bend elongation for the unwelded metal. In order to provide a possibility of making comparisons which shall hold for all plate thicknesses, the distance between reference points was chosen equal to the plate thickness and, in some cases, equal to half the plate thickness. The elongation in and near the weld seam was plotted diagrammatically, perpendicularly above each place in the bend. With unwelded samples, there was thereby obtained a uniform curve, both with bends of 90° and 180°; however, there existed no direct relation between the bend angle and the bend elongation. With welded seams, on the other hand, it was found that, in general, a non-uniform elongation in the transition zone and in the weld seam occurs, which, depending on the choice of the electrodes, may be very great. The differences between the bend elongation in the weld seam and in the plate as well as in the transition zone, may be explained by the different shape of the stress lines in the tension test. It is claimed also that, through choice of suitable electrodes, there may be attained a uniformity in the shape of the curve equal to that which characterizes the unwelded specimens. Whether, however, equal strengths or equal elongation limits are of decisive significance in this question, the authors do not state. Furthermore, the influence of the diameter of the pin around which the bend is made, on the distribution of the elongation was investigated. With decreasing ratio of the pin diameter to the plate thickness, there occurs a considerable increase in the weld seam elongation and in the elongation in the transition zone. Comparison tests made by the authors on the same material but with different electrodes led to the conclusion that the bend angle corresponding to the first crack and the elongation in the weld seam are not related to one another in any direct way but that the fitting of the electrode to the particular base metal leads to the most favorable elongation values.

H. Michel[17] deals with the elongation of welded joints in tension tests. In these tests, he investigates the behavior of the electrode material as affected by the influence of the base metal. The preparation of the samples was carried out in accordance with three different procedures. In the first form, on a plate to which, at its sides, two additional plates are joined, welding beads are deposited perpendicularly to the axis of the tensile specimen. In the second form, substantially the same procedure is retained but the weld beads are located parallel to the axis of the test specimen. In the third form, an ordinary V-weld is made by means of the particular electrode being investigated and with an opening angle of 90°, or the electrode material is melted into an angle iron of corresponding dimension. The third form of sample, that is to say, the customary V-weld, ought best to correspond to the conditions which occur in butt welding. A comparison of the elongation δ_5 showed the occurrence of no fundamental difference between the elongation values for the same elastic limits and the same tensile strengths. On the other hand, the contraction came out most favorably in the first and last-named forms of samples. Comparative tests,[18] which were carried out with the third form of test sample with V-joints on two materials with 0.16% C, 0.010% P and 0.032% S, or with 0.08% C, 0.100% P and 0.058% S, showed that the base metal does not influence the results of this test; elastic limit, tensile strength, elongation and contraction showed only minor differences. This permits of the conclusion that the procedure is useful for the testing of the electrode material in so far as the transition zone is not taken into consideration.

For carrying out free bend tests, the following proposal is made by F. S. Mapes and F. Howenstein.[19] The bend sample at first is supported horizontally on two rollers and is pressed by a stamp whose lower surface is so shaped as to contact the upper surface of the sample at two places which lie outside of the weld seam. By this device, the sample is subjected to a preliminary bend up to about 30°. After that the sample is mounted vertically and in that position is subjected to further bending between two compression members up to the appearance of the first crack, precautions being taken (by means of depressions in the bearing surfaces of the pressure blocks) that the ends of the sample shall not be displaced. In this way, it is stated to be possible to obviate the phenomena which appear when the load is applied at the middle and which have the result that the sample bends more in the base metal than in the weld seam.

A memorandum was prepared by the working committee of the Professional Committee for Welding Technique of the VDI in collaboration with the German Society for Technical Röntgen Ray Study of the German Society for Testing Technical Materials, regarding the utility of the known non-destructive test methods for weld connection.[20] As was repeatedly shown in the course of that report, the Röntgen process permits with adequate certainty, in the case of most welding procedures, the detection of pores and slag inclusions. Also the location of the fault can be definitely determined by stereoptic photographs. The only difficulties which arise are in the testing of fillet welds and of overlapped pressure (resistance) welds for joint faults. Röntgen ray investigations at the places where the welding work is executed offer, in general, rather considerable difficulties. The gamma ray method has the same possibilities as the Röntgen method; however, the ability to detect faults in thin and medium plate thicknesses is less. As a substitute for the Röntgen process, the gamma ray process comes into consideration only for parts which are accessible with difficulty. The especial advantages lie in the simple manipulation of the preparation.

The filings process can be employed with advantage in the testing of overlapped pressure (resistance) welds up to thicknesses of 2″, since it has good qualities as regards recognizing joint faults and cracks. However, its sensitiveness is only sufficient for faults which lie near the surface. For fusion welds on thick bodies, the process is not suitable. The magnetic acoustic process is not suitable for the recognition of faults but serves only for locating faults. Its possibilities are extremely dependent upon the skill of the individual making the test. The process is stated to be good for joint faults (in resistance welding). The possibilities of the milling process ought to be sufficiently known. The committee

recommends the combination of a non-destructive testing method with a seam-weakening method in order to detect faults and, when desirable, to remove them.

In the testing of weld connections of pipes, especially pipes already laid, a testing apparatus was developed in accordance with the following principles.[21] The apparatus consists of two rubber cushions for pressure control. These are in communication with a pipe serving as axis. This pipe is closed at one end; through the other end, an additional pipe is introduced for admitting a liquid or gas pressure. The test takes place between the two rubber cushions which are previously blown out with a definite pressure. The highest testing pressure for the weld seam is obviously controlled by the pressure in the rubber cushions. If the pressure remains constant during the test, it can be assumed that the weld seam is tight and free from fault.

A rapid process for determining the corrosion resistivity of weld connections was developed by A. Roux[22] in accordance with the fundamental principles of pressure measurements. Tests showed that with soft steel with less than 0.25% C and 0.1 to 0.8% Mn and with a soft weld material, the weld seam is anodic in dilute hydrochloric acid and also in sulphuric acid. While the current in sulphuric acid rises as a function of the time up to a maximum value; in hydrochloric acid, it falls slowly to zero. With a material with less than 0.20% C, 1 to 2% Ni and 0.5% Cr and Cu, the weld seam is cathodic in both electrolytes; the pressure sinks down to a value dependent on the property of the weld seam. With a material with 0.5 to 1.2% Mn, 0.5 to 1.0% Cr and 0.5% Cu, and a non-alloyed electrode, the weld seam is anodic and the voltage rises rapidly up to a maximum value. This process offers, as is the case with all tests with acids or salts, merely indicative data for the attacking material investigated. For judging of the corrosion in air or in acid-free water, it is not useful.

4. Characteristics of the Weld

The causes and the methods of decreasing internal stresses have been dealt with in the half year with which this report deals. H. Bühler and W. Lohmann[23] investigated the stresses in plates with gas fusion welding and arc welding and both for seam welding and repair welding. The internal stresses were determined in accordance with the drilling procedure. Fundamentally it was found that the amount of the stress for both these welding processes, i.e., gas welding and arc welding, is dependent in any case on the size of the welded piece, and it was also found that any unconditional superiority of one of the two welding methods, such as has been reported again and again by many investigators, does not exist. With small parts, gas fusion welding is to be preferred from considerations of the internal stresses; with large parts, arc welding often is superior. For repair welding likewise, the gas fusion welding process may be employed without difficulties while, with arc welding, stress cracks often occur. Especially with materials of great strength and with the use of covered electrodes, the danger of cracks is great while, with bare electrodes, the tendency toward cracks is less. It was shown that also in the first case, it is possible to obtain welds free from criticism and with low internal stresses, by appropriate arrangement of the seams and appropriate welding procedure. In many cases, it is to be recommended that, in repair work, the piece be subjected to a preliminary bending with a view to compensating for the subsequent distortion. For the removal of the internal stresses, it suffices to employ a heat treatment at 650° C., but in most welding work, it is not feasible to do this. In general, however, a considerable decrease in the internal stresses may be achieved simply by vigorous hammering of the welded seam.

In accordance with fundamental considerations about the occurrence of stresses, K. Liedloff[24] gives general rules for the avoidance of weld stresses. For this purpose, several procedures are suitable which relate to the preparation, the form of the construction part, the technical execution and the subsequent treatment of the weld seam. In the preparation, one should, as far as possible, impose by force upon the component piece, oppositely directed stresses as, for example, by previous curving in the case of repair welds or by the wedging up of cracks. Often considerable advantages are attainable also by preheating. From the constructional standpoint, all heaping up of weld beads should be avoided since, at those places, there appear strong peaks of stress. In many cases also, elastic kinds of construction may be utilized with advantage. The welding technique provisions comprise the choice of the filler rod, the number of layers, the speed of welding, the current strength or the flame size, the arrangement of the individual welding seams with reference to one another, and the cooling off procedure. The treatment, after completing the welding, with reference to the removing of internal stresses, may be considered as sufficiently understood. The methods which one has at one's disposal for overcoming these stresses are extremely numerous; however, it would be difficult to give instructions for each special case. It is necessary to have knowledge of the cause of the internal stresses in order to decide upon the most appropriate method of decreasing them.

Stress measurements on gas fusion welded drums made from boiler plate of 35 to 44 kg./mm.^{2} tensile strength were made by Ebel and Reinhard.[25] The welding of the drums was carried through as follows: Two curved sheets, after being joined with a longitudinal weld seam, were annealed up to 930° C. so as to be free from internal stresses and also in order to completely compensate both for the influence of the longitudinal seam and for the curvature. Pairs of drums of this kind were then joined together by a circumferential seam whereby the X-formed seam was welded simultaneously from the two sides. One boiler drum was in this way annealed from both sides with two welding burners while the other was normalized in a ring burner. The stresses were measured with the extensometer of E. Siebel and M. Pfender,[26] whereby, under retention of the assumptions necessary in stress measurements, the alteration in the distances between the measuring points was obtained as a measure of the stress alteration. The elastic deformation in the plate was measured perpendicularly to the circumferential seam on the outside, and parallel to the circumferential seam on the inside and outside. The tests showed that the step-by-step annealing with welding burners exercise an unfavorable influence on the stress distribution and the magnitude of the residual stresses. Thus, in the case of the seam annealed with welding burners, there were obtained residual tensile stresses of 18 kg./mm.^{2}, while other strips in the same zone even showed compression stresses in the weld seam. On the other hand, the residual stresses of the drums annealed in the ring heater were low and tolerably uniform.

Further investigations by O. Graf[27] dealt with the influence of the external and internal composition of the weld seams as well as with the influence of the weld stresses on the endurance strength. It was repeatedly indicated that joints should be formed free from notches; otherwise the endurance strength is very greatly decreased. This conclusion holds as well for butt as also for fillet welds so that definite general rules determined

in this way may be deduced for the form of the welded joints. This question is of decisive significance with fillet welds. Graf has indeed ascertained that, in general, narrow thick straps give considerably more favorable endurance strength than wide thin straps. Above all, satisfactory results were obtained by employing U-iron as strap profile. It has also been shown to be desirable to arrange fillet welds at a definite angle to the direction of tension, or, in certain cases, to employ also slot welds. For further improvement, it is, however, desirable with the above-named types of joints, to provide the ends of the welded seams with graduated transitions by machining them so that stress reversals and stress peaks may be avoided as much as possible. In judging of internal stresses due to welding, Graf proceeds from the fact that high static stresses are, as is well known, of but slight effect in decreasing the strength for pulsating loads. Internal stresses, which may be taken as corresponding to static loads of the welded seam, act in the same way. These results stand in agreement with the present reporters' own observations, according to which residual stresses in the material are greatly decreased and made no longer dangerous by continuous loading.

A. E. White, D. H. Corey and C. L. Clark[28] reported on a large number of tests which were carried out as preliminary investigations for the rebuilding of a steam power installation for a pressure of 46 atü and 450° C. steam temperature. The individual series of tests were carried through under the same conditions according to which the welding of the steam piping should follow. There were at their disposal a pipe steel with 0.33% C, 0.75% Mn and small aluminum and chromium contents, with a tensile strength of 51 kg./mm.², and another steel for steam valves and similar steel castings with 0.24% C, 0.36% Si, 0.62% Mn, 1.19% Ni, 0.82% Cr and 0.40% Mo, with a tensile strength of 71 kg./mm.² In these tests it was chiefly a matter of the testing of welded joints between pipes of 21.5 mm. thickness and 400 mm. diameter, and between pipes and castings of the above composition for their properties as regards strength, heat strength, endurance strength and notch toughness. The welding was carried out with covered electrodes which had a soft wire core and also were covered with organic materials to provide for the generation of a protective gas. All seams were heat treated for one hour at 600° to make them free from stresses, the heating being provided by induction. For the joint between pipes, there was obtained 90% of the strength of the pipe material; between pipes and castings, 85% of the strength of the pipe material and, on the average, 60% of the strength of the steel casting material. The elastic limit lay somewhat higher than that of the pipe material while the elongation in the 50 mm. reference length corresponded to that of the steel casting material. The data in the tables show that there were no differences between the test values in the different layers or with vertical and overhead welding. High temperature tensile tests were carried through corresponding to the steam temperature which was to be employed in service, namely 450°. Compared with the testing at room temperature, the pipe in these tests showed a strength of 40 kg./mm.²; the steel casting material, 61 kg./mm.²; the connection between pipes, 34.5 kg./mm.²; and between pipes and steel castings, approximately 36 kg./mm.², the connection between pipes, 34.5 kg./mm.²; and between pipes and steel castings 36 kg./mm.², approximately. The fracture occurred partly in the welded seam, partly in the transition zone. The endurance strength lay with all joints at about 7.4 kg./mm.² The notch toughness with the welded pipes was not decreased in comparison with that of the pipe material itself; on the other hand, in the case of joints between pipes and steel castings, it was somewhat less; however, still better than the notch toughness of the steel castings employed. With a testing temperature of 450°, there occurred a decrease in the notch toughness of 50 to 60% with the pipes and pipe connections while with the steel castings, it only amounted to some 30%. A 1000-hour heating of the materials and joints while stressed with a load of 4.9 kg./mm.² occasioned no change in the notch toughness. After chilling from 450°, there occurred partly a slight decrease in the notch toughness which, however, did not exceed 14% either with the base metals employed or with the weld joints. The excellent character of the weld seam was confirmed by Röntgen tests.

The investigations are the more remarkable because in Germany the possibility of welding materials with a tensile strength of 70 kg./mm.² with covered ferritic electrodes is widely disputed and very particularly with the very much more difficult conditions presented here with the partly vertical and partly overhead welding. That difficulties with these materials are to be expected is to be concluded from the fact that the authors recommend careful supervision of the materials in their manufacture, as also while they are being welded.

L. Miller and C. R. Deglon[29] investigated the influence of nitrogen on welded seams. From their investigations, they come to the following result. According to their opinion, the practical tests in no way confirm the harmful influence which has heretofore been ascribed to the high nitrogen content of the welded seam. For this reason, they do not ascribe any great significance to the generally usual process of determining the aging brittleness of welded seams by chilling in water from 600° C. For the removal of the nitrogen, they propose carrying out a heat treating process since it is known that nitrogen is already released from its combination at 800° C. and escapes as gas. According to previous tests of the present reporters, this possibility appears, so far as practical tests throw light on it, to be so doubtful as to require further investigation. Miller and Deglon consider as more harmful the influence in the welded seam of oxygen which arrives there from the air surrounding the arc. The small notch toughness of the welded seams is attributed by them chiefly to the oxygen content and less to the nitrogen content. The authors, however, do not give any consideration to the fact that the absorption of nitrogen and oxygen always proceeds in parallel and that, consequently, one cannot separate the influences of the two elements.

Endeavors to improve still further the economy of arc welding lead to the proposal to increase the current strength and thereby to decrease the melting time. The limits of this increase are in general imposed by the glowing of the electrode. So long as the glowing does not cause any deterioration of the melted down metal and of the joint, a high current strength may be employed. Tests in this direction were undertaken with alternating current of 50 cycles and with an o-load voltage of 85 volts[30] on two different types of covered electrodes of 4 mm. diameter, which, with customary welding conditions, gave good results. The test included the determination of the hardness, of the bending, of the notch impact resistances, and of the chemical composition, as well as microscopic investigations. With current strengths between 153 and 243 and also between 165 and 259 amperes, the hardness at first increased somewhat, but later, fell again slightly. The notch toughness and the bend elongation as dependent on the current strength, showed the same course. The chemical constitution showed according to the report, extremely small differences,

which could hardly have been expected since, with a change of the current strength, the penetration and therewith a greater influence exerted by the base metal on the chemical composition of the welded seam, is reasonable to expect. For the case under consideration, both electrodes would, therefore, permit of an increase of the current strength of about 80% as compared with customary conditions.

5. Behavior in Service

N. Wolkow[31] reports as follows as regards notable attempts to improve riveted constructions. In the case of a dredger, a large number of rivets had worked loose and could not be again drawn up tight without a great amount of work since it was a matter of a beam of box section. Therefore, investigations were made to provide good connections by welding modifications. The welding-over of the rivet holes gave, however, a good connection only at the upper edges while below the weld material, no connection resulted. This fault was overcome by cutting threads in the rivet holes, whereby a more favorable penetration even in the lower zones of the rivet holes was insured. For the actual final repair, therefore, the loose rivets were removed, threads were cut, the rivet holes were countersunk on both sides and the plates welded. It was practicable to carry the work through in a relatively short time without demounting the machines.

In connection with this should be mentioned tests by O. M. Harrelson and S. B. Plack,[32] who investigated the influence of repair work on I-beams. For this purpose, saw and flame cuts were made in the compression and tension flanges. Then these were joined together again by arc welding and measurements were made of the sag with various loads in comparison to that of non-welded I-beams. From these tests, it was found that in the elastic range, the sag with repaired I-beams was the same and, in some cases, was even less. Unfortunately, the tests were not continued up to fracture. It would be reasonable to assume that with repair work on flanges which, when undergoing bending, will endure tensile stresses, a lower fatigue stress is present.

Bibliographic References

[1] *Elektroschweissg.*, **5**, pages 161–164 and 193–196 (1934).
[2] *Z. VDI*, **78**, pages 1293–1294 (1934).
[3] J. Amer. Weld. Soc., **13**, No. 10, pages 16–28 (1934).
[4] *Z. Schweisstechn.*, **24**, pages 287–289 (1934).
[5] *Stahl u. Eisen*, **54**, page 1213 (1934).
[6] *Arcos*, **11**, pages 1081–1090 (1934).
[7] *Steel*, **94**, No. 20, pages 40–42 (1934).
[8] *Z. VDI*, **78**, S. 1126–1127 (1934); see also *Elektroschweissg.*, **4**, page 121 (1933).
[9] *Arcos*, **11** pages 1134–1135 (1934).
[10] *Arcos*, **11**, pages 1097–1101 (1934).
[11] *Elektroschweissg.*, **5**, pages 204–210 (1934); see also *Stahl u. Eisen*, **55**, pages 357–358 (1935).
[12] J. Amer. Weld. Soc., **13**, No. 7, page 11 (1934).
[13] *Autog. Metallbearb.*, **27**, pages 121–123 (1934); *Forsch.-Arb. a.d. Geb. d. Schweissens u. Schneidens*, **9**, F. (Halle a.d. S.: Carl Marhold 1934) pages 22–24.
[14] *Stahl u. Eisen*, **54**, pages 1212–1216 (1934).
[15] *Autog. Metallbearb.*, **27**, pages 115–121 (1934).
[16] *Arcos*, **11**, pages 1113–1119 (1934).
[17] *Arcos*, **11**, pages 1056–1061 (1934); see also *Stahl u. Eisen*, **54**, page 1214 (1934).
[18] *Arcos*, **11**, pages 1158–1160 (1934).
[19] J. Amer. Weld. Soc., **13**, No. 10, pages 28–30 (1934).
[20] *Z. VDI*, **78**, page 965 (1934).
[21] *Z. Schweisstechn.*, **24**, pages 245–247 (1934).
[22] *C. R. Acad. Sci.*, Paris, **198**, pages 2095–2098 (1934).
[23] *Elektroschweissg.*, **5**, pages 141–145, 165–170 and 221–229 (1934); see also *Stahl u. Eisen*, **55**, pages 240–242 (1935).
[24] *Masch.-Bau*, **13**, pages 593–96 (1934).
[25] *Autog. Metallbearb.*, **27**, pages 305–310 (1934); *Forsch.-Arb. a. d. Geb. d. Schweissens u. Schneidens*, **9**, F. (Halle a. d. S.: Carl Marhold 1934) pages 118–123.
[26] *Arch. Eisenhüttenwes.*, **7**, pages 407–415 (Werkstoffaussch. 250) (1933–34).
[27] *Z. VDI*, **78**, pages 1423–1427 (1934).
[28] J. Amer. Weld. Soc., **13**, No. 9, pages 3–11 (1934).
[29] *Iron Steel Ind.*, **7**, pages 181–185 and 279–280 (1934).
[30] *Arcos.*, **11**, pages 1160–1164 (1934).
[31] *Techn. Zbl. prakt. Metallbearb.*, **44**, pages 384–387 (1934).
[32] J. Amer. Weld. Soc., **13**, No. 7, pages 30–31 (1934).

The Behavior of Fillet Welds When Subjected to Bending Stresses*

By NORMAN G. SCHREINER†

Synopsis

THE following report presents the results of tests of fillet welds under loading conditions to which they are commonly subjected, namely, those giving rise to combined bending and shearing stresses in the weld. The welds investigated covered lengths from $1^1/_2$ to 10 in. and fillet sizes of $^3/_8$ and $^1/_2$ in. Two types of lightly coated and two types of heavily coated electrodes were included in the twenty-seven specimens tested. The loads were applied in such a manner that in approximately half the specimens the welds were under pure bending moment, while the other specimens, the duplicates of the first group, were loaded so that the welds were subjected to bending moment and vertical shear. In addition tensile tests on specimens cut entirely from the fillet welds were made, from which the physical properties and specific gravity of this deposited metal were determined. The ultimate bending moments observed are plotted against the section modulus and are compared with the calculated resisting moments of the welds. It is shown that the ratio of the modulus of rupture of the welds to their ultimate strength, as determined by the standard end-fillet qualification specimen, averages 1.87 for lightly coated electrodes and 1.61 for heavily coated electrodes. The results of the second series, in which the welds were subjected to average vertical shears up to eighty per cent of their ultimate shearing strength, show very little decrease in bending resistance in comparison with similar specimens in which no vertical shear was present.

The chief conclusions that are drawn on the basis of these results are:

1. That the factor of safety, the ratio of the observed ultimate strength to the designed strength, of welds subjected to combined bending and shearing stresses in these tests is at least seven.
2. That the vertical shearing stresses in the weld are of small importance in comparison to the bending stresses. As long as the weld is adequate to resist the bending, it is adequate for vertical shears of the magnitude allowed by present specifications, and will still give a factor of safety of seven.
3. That the use of heavily coated electrodes increases the bending resistance of the weld in approximately the same proportion as the tensile resistance is increased.
4. For the $^3/_8$ and $^1/_2$-in. fillet welds tested, the bending resistance increases directly as the increase in fillet size.

* Report rendered to Structural Steel Welding Committee, A. B. W.

† Structural Steel Welding Committee Research Fellow, Lehigh University, Bethlehem, Pennsylvania.

I. Introduction

1. *Purpose:* The investigation reported in this paper arose from the difficulties in determining the stresses in the welds used in the seat angle investigation of 1934[1].** in accordance with the observed data and the knowledge of weld behavior then available. It was carried on under the auspices of the Structural Steel Welding Committee of the American Welding Society†† in cooperation with the Fritz Engineering Laboratory at Lehigh University. The steel used in the investigation was furnished through the courtesy of the Bethlehem Steel Company.

2. *Acknowledgment:* Acknowledgment is made to the Structural Steel Welding Committee, Messrs. L. S.

**These numbers apply to references given at the end of this report.

††Formerly Structural Steel Welding Committee of the American Bureau of Welding.

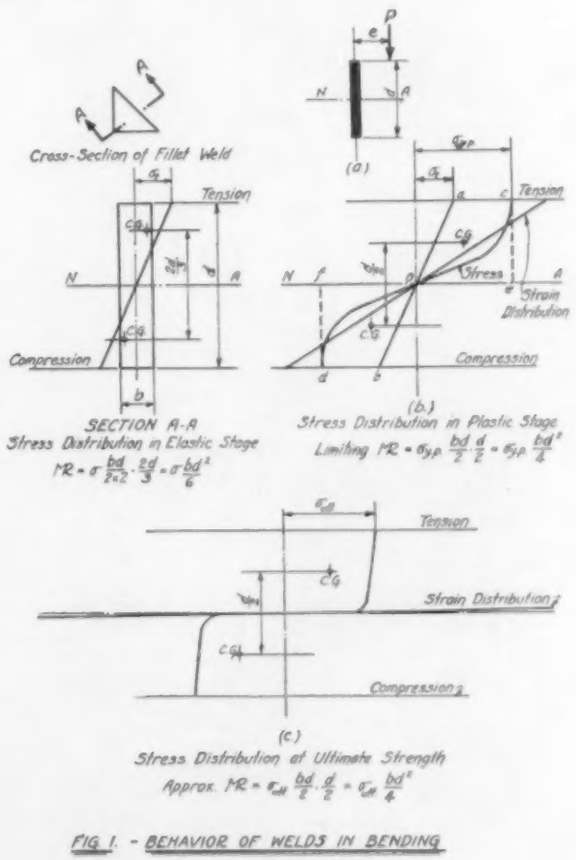


FIG. 1. - BEHAVIOR OF WELDS IN BENDING

Moisseiff, chairman, William Spraragen, secretary, for their continued interest; to the Bethlehem Steel Company for furnishing the steel; to the members of the laboratory staff for their valuable assistance in the fabrication and testing of the specimens and to Inge Lyse, Research Associate Professor of Engineering Materials, Lehigh University, for his continued cooperation and valuable advice during the progress of the investigation.

II. Common Theoretical Considerations

Fillet welds under the influence of loadings producing bending moments are generally designed by the use of the ordinary theory of flexure. Let the rectangle in Fig. 1*a* represent some longitudinal cross section of a fillet weld. We will then consider the neutral axis, *NA*, coincident with the gravity axis. The load P is applied at an eccentricity, e, from the weld. The section is now subjected to a bending stress due to the moment Pe and to vertical shearing stress due to the load P. The correct value to use for e is not well established; it may be the dimension from P to: (*a*) the center of gravity of the weld cross section, (*b*) the center of the leg of the fillet or (*c*) the root of the weld. Whichever it may be is of small importance, unless the difference between the values is large in comparison to the total lever arm.

Applying the flexure formula, the bending stress σ_t may be evaluated:

$$\sigma_t = \frac{Pe}{\frac{bd^2}{6}} = \frac{6Pe}{bd^2} \qquad (1)$$

and the average shearing stress σ_s may be evaluated:

$$\sigma_s = \frac{P}{bd} \qquad (2)$$

If b is assumed of unit dimension, the values for the internal resisting forces will be given in pounds per linear inch.

The common method of analysis, simple in application and included here for these reasons although admittedly an approximation, is to combine the two forces vectorily and call the resultant, σ, the maximum stress per linear inch, or:

$$\sigma = \frac{P}{d}\sqrt{\frac{36e^2}{d^2} + 1} = \frac{P}{d}\,\frac{\sqrt{36e^2 + d^2}}{d} \qquad (3)$$

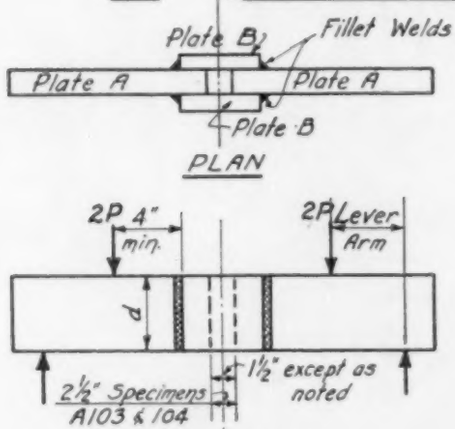
From the theory of combined stress, the maximum principal stress σ is given by:

$$\sigma = \frac{\sigma_t}{2} + \sqrt{\sigma_s^2 + \frac{\sigma_t^2}{4}} = \frac{P}{d}\left(\frac{3e}{d} + \frac{\sqrt{9e^2 + d^2}}{d}\right) \qquad (4)$$

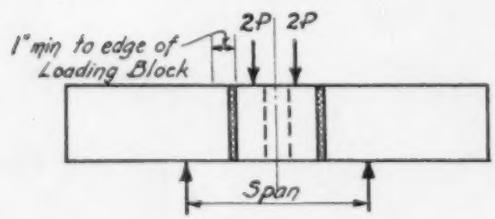
It will be noted that by either method the load P depends upon the allowable unit weld stress σ, the length of the weld and the eccentricity of the load. Present design practice uses a value of σ equal to the allowable stress in pounds per linear inch given by the welding codes, and then assumes a factor of safety of at least four based upon the ultimate strength of the weld.

The above formula assumes that the bending stress in a fiber varies directly as its distance from the neutral axis, commonly known as a triangular distribution of stress, Fig. 1*b* line *aob*. This is true below the yield point of the material, but as the yield-point stress on the extreme fibers is reached, they stretch without any

FIG. 2 – TEST PROGRAM – SERIES A & B



ELEVATION
Showing Loading of Series A Specimens



ELEVATION
Showing Loading of Series B Specimens

NOTE:- Bearing surfaces to be machined plane & parallel
Welding to be on machined edges

SPECIMEN SCHEDULE – SERIES A

Spec No.	Weld Data Size	Weld Data Type	Depth d	Two (2) of each Plates A	Two (2) of each Plates B	Lever Arm
A13	3/8"	Bare	1½"	1¼ x 1½ x 10"	¾ x 1½ x 4½"	3"
A33	3/8	"	3	1¼ x 3 x 11"	¾ x 3 x 4½"	4"
A63	3/8	"	6	1½ x 6 x 13"	⅞ x 6 x 5½"	5"
A103	3/8	"	10	1½ x 10 x 18"	⅞ x 10 x 7"	10"
A14	½	"	1½	1¾ x 1½ x 10"	1 x 1½ x 4½"	3"
A34	½	"	3	1¾ x 3 x 11"	1 x 3 x 4½"	4"
A64	½	"	6	2 x 6 x 13"	1¼ x 6 x 5½"	5"
A104	½	"	10	2 x 10 x 18"	1¼ x 10 x 7"	11"
A13D	3/8	Coat'd	1½	1¼ x 1½ x 10"	¾ x 1½ x 4½"	3"
A33C	3/8	"	3	1½ x 3 x 11"	¾ x 3 x 4½"	4"
A63C	3/8	"	6	1½ x 6 x 13"	⅞ x 6 x 5½"	5"
A64D	½	"	6	2 x 6 x 13"	1¼ x 6 x 5½"	5"

SPECIMEN SCHEDULE – SERIES B

Spec No.	Weld Data Size	Weld Data Type	Depth d	Two (2) each of Plates A	Two (2) each of Plates B	Span
B13	3/8"	Bare	1½"	1¼ x 1½ x 10"	¾ x 1½ x 4½"	12"
B33	3/8	"	3	1¼ x 3 x 11"	¾ x 3 x 4½"	18"
B63	3/8	"	6	2 x 6 x 13"	1¼ x 6 x 5½"	9"
B103	3/8	"	10	2 x 10 x 18"	1¼ x 10 x 7"	15"
B14	½	"	1½	1¾ x 1½ x 10"	1 x 1½ x 4½"	12"
B34	½	"	3	1¾ x 3 x 11"	1 x 3 x 4½"	8"
B13C	3/8	Coat'd	1½	1¾ x 1½ x 10"	1 x 1½ x 4½"	7½"
B33D	3/8	"	3	1¼ x 3 x 11"	¾ x 3 x 4½"	8½"
B63C	3/8	"	6	2 x 6 x 13"	1¼ x 6 x 5½"	9½"

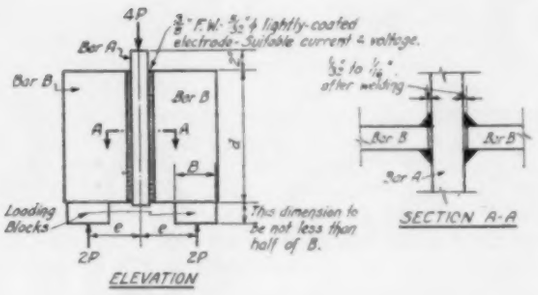
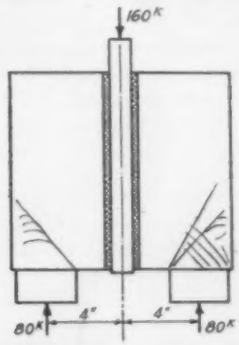


TABLE OF SPECIMENS

Specimen No.	Length of Weld - d in.	Lever Arm - e in.	Bearing B - in.	Bar A Main Plate	Bar B Wing Plates
C62	6.25	2	3	1 Pl - 6" x 1/2" x 8 1/4"	2 Pls - 3 1/2" x 3/8" x 6 1/4"
C124	12	4	3 5/8	1 Pl - 8" x 1 1/2" x 14"	2 Pls - 6" x 1/8" x 12"



APPEARANCE OF SCALING OF WHITEWASH - C 124 - LOAD 160 Kips
Scale 1:50

FIG. 3 - SPECIMENS C62 & C124

further application of load and the stress distribution diagram takes the form of *cod*. Not so the strain distribution which is planar throughout the full loading range because of the necessity of the parts fitting together. The fibers nearer the neutral axis progressively reach the yield-point stress and the limiting shape of the distribution curve is *ceofd*. At this stage the expression for the resisting moment is

$$MR_{yp} = \sigma_{yp} \frac{d^2}{4} \tag{5}$$

which is fifty per cent greater than the resisting moment at the yield point before plastic yielding took place.

When plastic yielding ceases due to strain hardening of the material, the resisting power increases. The shape of the stress distribution curve is not exactly known but must be somewhat similar to that indicated in Fig. 1*c* while the strain distribution is still a straight line. Thus we still have essentially a rectangular distribution of stress and the ultimate resisting moment may be expressed by:

$$MR_{ult} = \sigma_{ult} \frac{d^2}{4} \tag{6}$$

In mechanics of materials the modulus of rupture is a fictitious measure of the ultimate unit stress on the extreme fiber at the point of maximum moment. This value σ_m, as given by the flexure formula based on triangular distribution of stress is:

$$\sigma_m = \frac{6M_{max}}{d^2} \tag{7}$$

hence is one and one-half times σ_{ult} given by equation (6) which is based on the rectangular stress distribution.

III. Test Program

1. *Object*—With these fundamentals in mind the test program was laid out to ascertain:

(*a*) The factor of safety of welds in bending using present methods of design.

(*b*) The validity of the present design methods.

(*c*) The stress distribution in the welds.

(*d*) The physical properties of the weld metal and their effect on weld behavior.

2. *Specimens*—The specimens may be divided into three groups:

(*a*) Fillet welds under pure external bending moment, hence under zero vertical shear. These are designated as Series A (Fig. 2) in which group sixteen specimens were tested. They were made up of two main plates and two splice plates ranging in depth from 1.5 to 10 in., the welds being placed along the full depth of the splice plates. The plates were designed so that the unit stresses would be below the yield point when weld failure occurred. Except for slight local yielding this requirement was maintained throughout the investigation.

(*b*) Fillet welds under transverse bending. These specimens are designated as Series B (Fig. 2) and were nine in number. They were companion specimens to Series A, similar in material, size and fabrication.

This group also contained two specimens designated C 62 and C 124 as shown in Fig. 3. The wing plates in each specimen were so small in cross-sectional area that failure in the welds was impossible before the plates yielded to such an extent as to be worthless as agencies for the transferal of the applied load.

(*c*) The physical tests were carried out on tensile bars machined entirely from fillet weld metal in accordance with Fig. 4. The physical constants determined for each

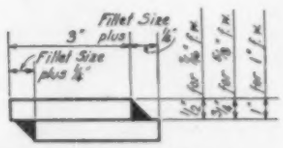
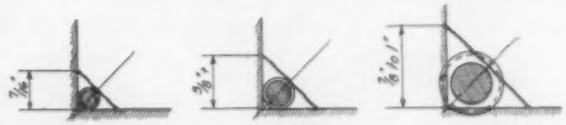


PLATE SCHEDULE

Weld Size	No. of Pl. Req.	Size of Plates
1/4"	6	1/2 x 3 x 9"
3/8"	6	3/4 x 3 x 9"
1"	2	1 x 3 x 9"

WELD DEPOSITION PLATES

NOTE:- Welding electrodes, both "bare" and heavily-coated to be 3/16" dia. Discard approx. 1" from each end of fillet. Welding to start at one end and finish at opposite end. Craters to be filled



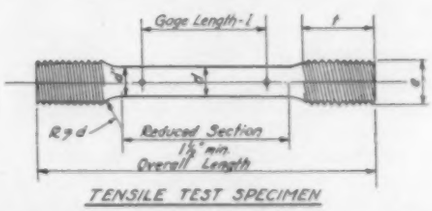
Bare Electrode - Single Pass
Heavily-Coated - Three Pass
Diameter of Tensile Bar 3/16"

Two - Pass
Six - Pass
5/16"

Six Pass
1/2" (0.505")

LOCATION OF TEST BARS IN FILLET WELDS (Full Size)

FIG. 4 - TEST SPECIMENS - SERIES C



TENSILE TEST SPECIMEN

DIMENSIONS

Nominal Size	Dia. at Center - d	Dia. at Fillet d'	Gage Length - l	Reduced Section	Dia. at End - e	Threaded Length - t	Threads per inch	Overall Length
3/16"	0.188 ± 0.001	d + 0.001	3/4"	1 1/2"	1/4"	1/2"	20	2 3/4"
5/16"	0.313 ± 0.002	d + 0.002	1 1/4"	1 1/2"	3/8"	3/4"	16	3 1/2"
1/2"	0.500 ± 0.005	d + 0.004	2"	2 1/4"	5/8"	1"	10	4 1/2"

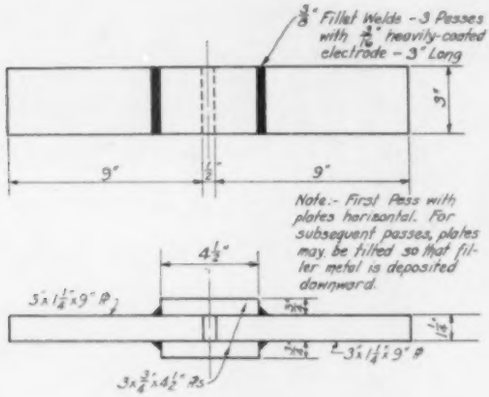

3/8" Fillet Welds - 3 Passes with 1/4" heavily-coated electrode - 3" Long
3"
9"
1/2"
9"
Note:- First Pass with plates horizontal. For subsequent passes, plates may be tilted so that filler metal is deposited downward.
4 1/2"
3 x 1 1/4 x 9" PL
3 x 1 1/4 x 9" PL
3 x 3/8 x 4 1/2" PL

FIG 5 MODIFIED QUALIFICATION SPECIMEN FOR HEAVILY-COATED ELECTRODE WELDS.
2 Reqd for each type of electrode

specimen consisted of Johnson's apparent elastic limit (the point on the stress diagram at which the rate of deformation is fifty per cent greater than it is at the origin), yield strength (stress at which the material exhibits a 0.2 per cent permanent set), ultimate strength, per cent elongation in two inches, per cent reduction in area, modulus of elasticity and specific gravity.

(*d*) The welds were electric arc welds using both lightly coated and heavily coated electrodes. Two types of each electrode were used, *A* and *B* lightly coated $^{5}/_{32}$-in. and $^{3}/_{16}$-in. diameters; and *C* and *D* heavily coated, $^{3}/_{16}$-in. diameter.

All welding was done in the laboratory shop under direct supervision. The strength of the fillet welds of the lightly coated electrodes was determined by means of the standard $^{3}/_{8}$-in. end-fillet welded qualification specimen (Code for Fusion Welding and Gas Cutting in Building Construction—Code 1 Part A—1934, American Welding Society, Appendix II). The average ultimate strength for Electrode *A* was 13,800 lb. per lin. in.; for Electrode *B* was 15,350 lb. per lin. in. The D.C. arc characteristics were: voltage 15–18, amperes 160–200.

The strength of the welds made with the heavily coated electrode was determined by means of a modified end-fillet welded specimen shown in Fig. 5. The average ultimate strength for both types of electrode was 18,900 lb. per lin. in. D.C. arc characteristics were: voltage 24–30, amperes 200–220.

In multilayer welding the previous layers were carefully cleaned of scale and slag by means of a chisel and stiff wire brush before adding the next layer. The slag due to the heavily coated electrodes was allowed to thoroughly freeze and cool slightly before being removed, but in all cases the succeeding passes were laid while the preceding pass was still hot.

The welds were carefully gaged and without exception were within the designed limits of minus 0 plus $^{1}/_{8}$ in. and quite uniform results were obtained.

3. *Test Methods*—The specimens of Series A and B were tested in the 300,000-lb. capacity Olsen or 800,000-lb. capacity Riehle screw-power testing machines in the Fritz Engineering Laboratory. The specimens of Series C were tested in a 50,000-lb. capacity Riehle and 20,000-lb. capacity Olsen screw-power testing machine. The screws of the 300,000 and 800,000-lb. machines were motor driven, moving the head of the machine at a speed of 0.05 in. per min. The smaller machines were driven by hand-power, moving the head a smaller and somewhat indeterminate amount, although every effort was made to keep the speed constant.

The load was applied to specimens of Series A and B, shown in Fig. 6, through a spherical bearing block and a loading beam to the specimen. Rollers were used so that there would be a minimum of lateral or longitudinal restraint due to the loading apparatus and especial care was taken so that the loads were accurately placed. The specimen was protected from crushing and the load distributed by blocks between the rollers and the specimen.

Observations on the specimens of Series A consisted of the determination of the position of the neutral axis by means of 10-in. Whittemore strain gage observations, an attempt at determining the stresses in the plates by the use of Huggenberger tensometers, determination of strains in the tension ends of the welds by the use of Huggenberger tensometers over a $^{1}/_{2}$-in. gage length and determinations of the center deflections of the whole specimen by the wire-mirror-scale method. The observations on Series B specimens were confined to the measurement of center deflections because the method of loading did not allow sufficient clearance for the placing of instruments.

All specimens of Series A and B, C 62 and C 124 were coated before the test with a thin layer of hydrated lime and water which assisted materially in the determination of points of yield.

The determination of the strains for the stress-strain curve of the Series C specimens was made with the Huggenberger tensometers over a one-inch gage length and each value is the average of diametrically opposite tensometer readings.

In all tests sufficiently small increments of load were

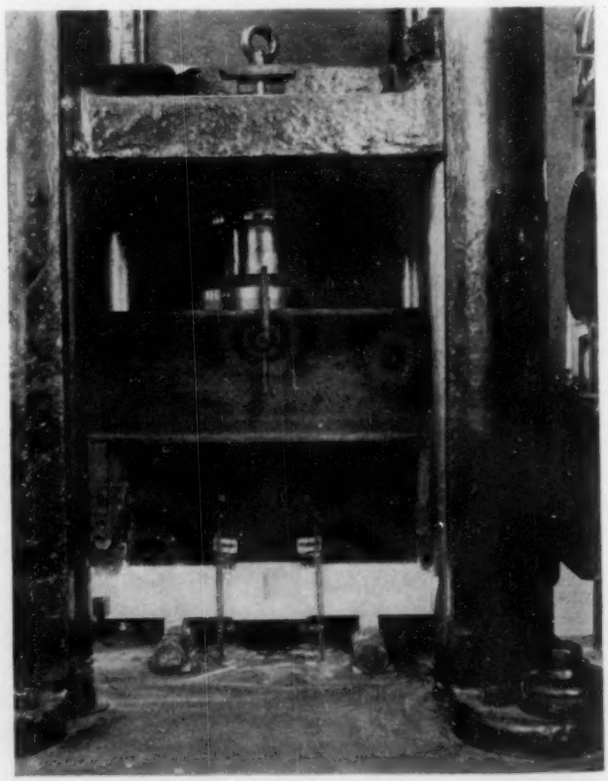


Fig. 6—Specimen A 34 Set-Up in Pure Bending in 300,000-Lb. Machine

taken to assure a minimum of six observations below the proportional limit and as many points thereafter as the condition of the specimen or the range of the instruments would allow.

The specific gravity of the electrode and of the tensile specimens cut from the weld was determined from their weight and volume. The electrodes were cleaned of all coating and polished to a smooth surface; the tensile specimens were thoroughly degreased by the use of various solvents. The weight was determined to the ten-thousandth of a gram on a Chainomatic balance and then rounded off to the nearest hundredth. The volume was determined by the displacement of alcohol in a standardized burette to a hundredth of a cubic centimeter. Alcohol was used instead of water because it wet the specimen more easily and there was less likelihood of including air bubbles in the volume determination. The specific gravities are thus accurate to the second decimal place except in the smaller specimens where the error may approach five per cent. The weights varied from 7.70 to 187.24 grams and the volumes from 0.99 to 24.66 cu. cm.

IV. Test Data

1. *Series A*—(*a*) The test results of this series are presented in Table I, Columns 3 to 5.

Column 3 was determined from observation of the scaling of the whitewash on the surface of the weld. Without exception this occurred on the compression side first, near the end of the weld. The reason for this is not readily apparent since the loading blocks were at a sufficient distance from the weld to prevent local stress disturbance and it is generally considered that the compression yield point is at least equal to that in tension.

Column 4 was determined from observation of the points on the moment-weld strain curve, designated τ, or moment-center deflection curve, designated Δ, at which the inclination of the tangent to the curve was fifty per cent greater than the initial inclination.

Sometimes the specimen gave warning of impending failure by a drop of the beam of the testing machine at about 95 per cent of the ultimate load, but generally there was no definite yield of the weld metal without further addition of load. The ultimate applied moment is given in column 5.

Columns 6 and 7 give, respectively, the calculated modulus of rupture and the ultimate stress based on full rectangular distribution.

(*b*)—It was with A 33 that the investigation had its inception. The original specimen was made up as a standard $^3/_8$-in. end-fillet welded qualification specimen and loaded to give pure bending across the welds as indicated in Fig. 2.

Measurements over a ten-inch gage length which included the main plates, welds and splice plates, were taken with a Whittemore gage. The average strain so measured was sixteen per cent in excess of that calculated by the flexure formula.

Measurements were taken of the tensile and compressive strains in the main plates by means of tensometers placed as close to the weld as was conveniently possible. These measurements established the fact that the neutral axis was coincident with the gravity axis in the parent metal very close to the weld, from which it is safe to conclude that the neutral axis of the weld is also its gravity axis. From these measurements an indication of the high skin-stress near the welds was noted. The measured strains on the main bar were approximately seven per cent in excess of those calculated, while those on the splice plates were twenty-one per cent *less* than the calculated.

The stress in the main bars soon reached the yield point and great increases in vertical deflection occurred at a bending moment of only 24,600 in.-lb. Increasing the load resulted in such greatly increased deflections that the test had to be abandoned at a bending moment of 30,600 in.-lb. On the basis of the common theory this corresponds to a weld stress of 20,400 lb. per lin. in. At

TABLE I - TEST RESULTS - SERIES A

Specimen Number	Length of Weld in.	Bending Moment Per Weld At: Scaling of Whitewash in-lb	Yield Point by Observation of Curves in-lb	Ultimate in-lb	Modulus of Rupture σ_m lb/lin in	Ultimate Stress $\sigma_{ult.}$ lb/lin in	Ratio Calculated to Measured Stress	Intersection of Calculated and Observed Strains: Stress lb/sq in	Intersection of Calculated and Observed Strains: Bending Moment in-lb	Ratio Scaling / Ultimate	Factor of Safety
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
A 13	1.52	8,424	4,425$^\tau$	9,435	24,900	16,600	1.62	36,000	6,870	89.5	8.3
A 14	1.51	10,800	5,850$^\tau$	12,250	32,400	21,600	1.65	36,850	9,000	88.2	8.1
A 33-2	3.03	27,160	22,800*	35,400	23,200	15,500	--	--	--	76.9	7.7
A 33-3	3.02	33,360	29,800*	38,500	25,400	16,900	--	--	---	86.0	8.5
A 34-1	3.00	36,400	22,000*	38,820	25,800	17,300	1.78	35,900	32,000	93.5	6.5
A 34-2/	2.94	44,000	25,600$^\tau$	54,800	38,000	25,400	1.61	37,400	40,600	80.4	9.5
A 63-1	6.00	92,100	69,000$^\tau$	117,500	19,700	13,200	1.64	35,800	97,500	78.4	6.6
A 63-2/	5.91	126,900	81,500$^\tau$	181,150	31,000	20,700	1.63	36,900	121,850	70.0	10.3
A 64	6.00	117,250	68,500$^\tau$	158,150	26,400	17,600	1.65	35,700	121,000	73.7	6.6
A 103	10.00	325,000	237,000$_\Delta$	463,000	27,700	18,500	--	--	--	70.2	9.2
A 104	10.00	390,600	346,500$_\Delta$	586,355	35,200	23,500	--	--	--	66.7	8.8
A 13D	1.50	5,370	3,660$^\tau$	10,530	28,060	18,800	1.63	39,000	5,030	51.0	7.5
A 33C	3.00	27,520	26,800$^\tau$	50,730	33,700	22,600	1.69	40,800	34,200	54.1	9.0
A 63C	5.82	---	93,000$^\tau$	168,350	29,700	19,800	1.62	42,000	133,250	79.4	7.9
A 64D	6.00	156,150	94,000$^\tau$	261,400	43,500	29,000	1.61	41,000	149,750	59.5	8.7

/ Electrode B used. Other specimens of Electrode A except as noted.
$^\tau$ From weld strain data by tensometers
* By strain gage over 10-in. gage length specimen including welds
$_\Delta$ By center deflection readings

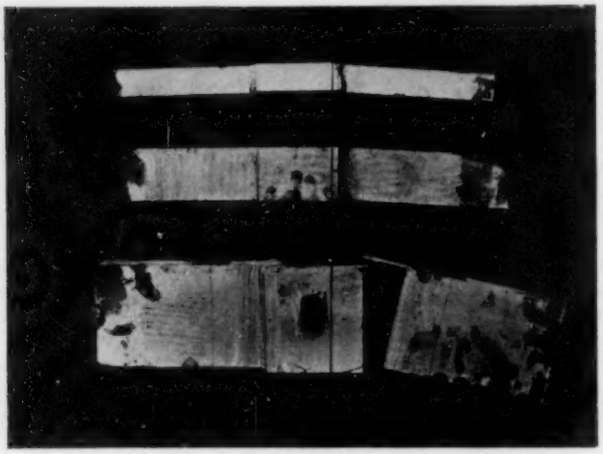


Fig. 7—Set of Series A Specimens—Lightly Coated Electrode—$^1/_2$-in. Fillet Welds

this point all welds showed slight cracks at the root, and some scaling of the whitewash on the surface.

The specimen designated A 33-2 was then made up using 3 in. by $1^1/_4$-in. main bars and 3 in. by $^5/_8$-in. splice bars. Readings over the ten-inch gage length again gave average strains in excess of the calculated but again proved the location of the neutral axis as coincident with the gravity axis. Tensometers in the same location as in the above test showed similar results, the strains in the main plates being almost coincident with those calculated, while those on the splice plates were now 33 per cent *less* than those calculated.

In this specimen too the splice plates yielded at about seventy per cent of the ultimate load but they soon hardened sufficiently that the load could be increased to failure of the welds without excessive yielding of the plates.

A third specimen A 33-3 was then tested in which the splice plates were $^3/_4$ in. thick and no distress was evident in any of the plates at the ultimate load. Accordingly the remaining specimens were designed with the maximum bending stresses in the main plates limited to 30,000 lb. per sq. in. The area of the splice plates was then made approximately twenty per cent greater than that of the main plates. With this design little difficulty was experienced due to yielding of the parent metal.

Tensometer readings on the plates and with the Whittemore gage were again taken on this specimen and it was felt that the following was established.

(*a*) The coincidence of the neutral axis of the weld with its gravity axis.

(*b*) The existence of skin stresses of unknown magnitude in the parent metal adjacent to the weld. This finding was corroborated in all succeeding tests but no means were taken to determine their magnitude.

Figure 7 shows a group of specimens with $^1/_2$-in. fillet welds from a lightly coated electrode. From top to bottom they are designated A 14, A 34 and A 64. A typical performance of all specimens welded with a lightly coated electrode may be described as follows. The loads were slowly applied and readings of the instruments taken until the deflections were beyond their range or failure seemed imminent. Cracking of the mill scale on the inside of the splice plates was observed at loads of less than fifty per cent of the ultimate, revealing a high skin stress in this part of the plates. Scaling of the whitewash was first noted on the surface of the weld under compressive stress at about 86 per cent (Table I, col. 11) of the ultimate load in the case of the specimens 1.5 and 3 in. deep. This occurred practically simultaneously over the full length of the welds. With only slightly greater deflection the welds fractured suddenly.

In the specimens 6 and 10-in. deep scaling on the compressive surface at the weld occurred at approximately 72 per cent of the ultimate load close to the end of the weld and as the loading continued the scaling proceeded toward the neutral axis. No great deflection was possible in these specimens either and they too failed suddenly. Where the fusion between the weld and parent metal was perfect, fracture occurred through the throat of the weld; where fusion was imperfect the fracture was along the line which was imperfectly fused.

The photographs of A 14 and A 34 illustrate very well the type of throat fracture on the right of the specimen, and the scaling of the whitewash on the left hand welds. A 64 illustrates the progressive scaling of the weld sur-

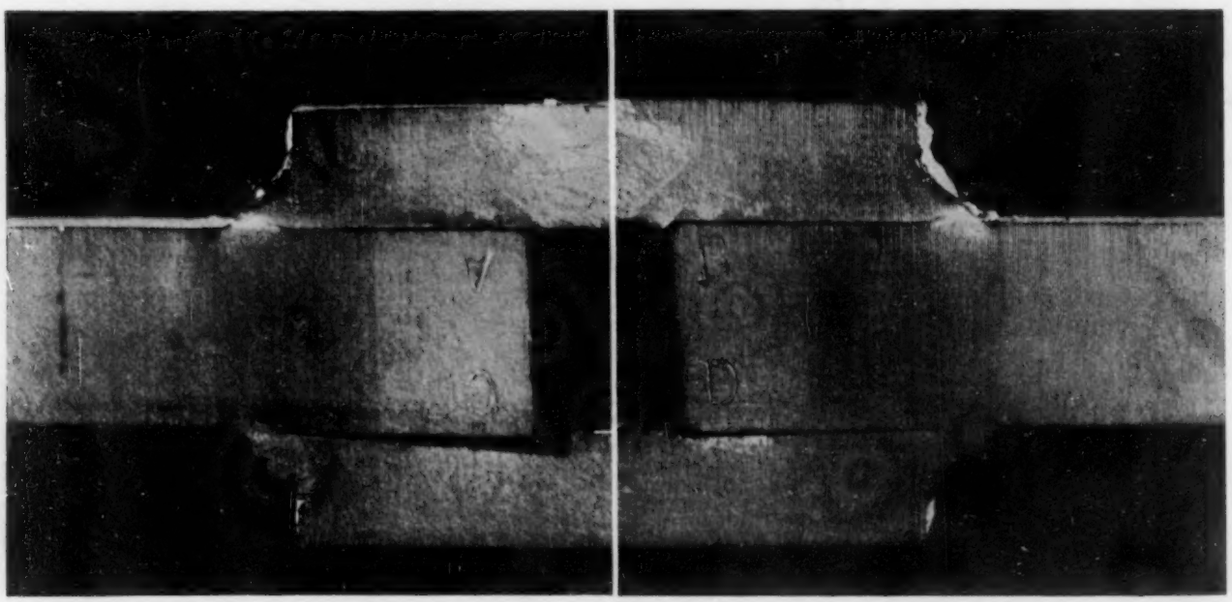


Fig. 8—Showing Ductility of Heavily Coated Electrode Welds—Tool Lines Originally Straight—Specimen A 13D

TABLE II

TEST RESULTS - SPECIMENS C 62 AND C 124

WELDS OF ELECTRODE A

	(1)	Specimen No.	C 62	C 124
	(2)	Average Gap in.	0.039	0.045
	(3)	Fillet Size in.	0.336	0.330
Total Load (pounds) at	(4)	Scaling of Wing Plates	52,700	130,000
	(5)	General Yielding of Wing Plates	118,000	---
	(6)	Cracks in Weld	140,000	250,000
	(7)	Gap Closure Complete at One End	132,000	271,000
	(8)	Final Load	180,000	271,000
Calculated Stresses At Final Load lb per sq in — Wing Plates	(9)	Shearing	23,100	12,900
	(10)	Bearing	48,000	42,800
Calculated Stresses At Final Load lb per sq in — Maximum Weld Stresses	(11)	Cracks	12,100 51,000*	11,650 50,000*
	(12)	Final Load	15,600 65,700*	12,650 54,200*

*Stresses in pounds per square inch over net throat section

face on the left and the failure due to lack of fusion in the weld on the right. Repeat tests were made on specimens showing lack of fusion and the results of the original tests were discarded.

Specimens welded with the heavily coated electrode behaved differently. The scaling of the whitewash on the weld surface occurred at about sixty per cent of the ultimate load near the compressive end of the weld, and generally along the toe at the main plate. This scaling proceeded progressively toward the neutral axis. Considerable deflection was recorded before the ultimate load was reached (in Specimen A 13D a center deflection of $1^1/_2$ in. in an 18-in. span) and the fracture was very gradual, the weld metal exhibiting great tenacity. The fracture proceeded from the root of the weld at a flat angle to the main plate. The metal was finely-grained, almost free from inclusions and blow-holes and the fractured surface was silky in texture.

Figure 8 is an example of the ductility of these welds. This shows the tension ends of the welds on Specimen A 13D. The machine tool marks were originally straight lines directly across the specimen. The photograph shows the considerable distortion of the weld metal and only slight cracks at the root of the weld.

The tensometer readings across the weld were plotted as applied bending moment against strain in the weld. Because of the great amount of data taken only a typical curve is presented in Fig. 9. The curve is of the same type as the stress-strain diagram for the weld metal. The point at which the inclination of the tangent becomes fifty per cent greater than the initial inclination is designated as the yield point. The moment corresponding to this point is given in column 4 of Table I and in column 5 of Table III. These values are identified by the τ which follows the number. The moments average about fifty per cent of the ultimate moment. The stress at this point determined by the measured strain and the stress-strain diagram of the weld metal corresponds very well with the Johnson limit of the weld metal. The average strain, calculated by the ordinary method discussed in section II, is also plotted and is always from 61 to 69 per cent greater than the measured strain. The ratio of calculated strain to measured strain is given in column 8 of Table I. The line determining the calculated strain intersects the plotted measured strain at a point corresponding to the unit stress given in column 9 of Table I. The applied bending moment corresponding to this point is given in column 10. It will be noted that these stresses of column 9 correspond closely to the yield strengths of the weld metal and the corresponding moments of column 10 to the moments at which scaling was first observed on the surface of the weld, column 3.

In Series B, tensometer readings of this nature were

TABLE III - TEST RESULTS OF SERIES - ELECTRODE B WELDS EXCEPT AS NOTED

Specimen Number	Length of Weld "d" in.	Lever Arm To Center Of Weld "e" in.	Bending Moment Per Weld At			Average Shear At Ultimate Load lb/lin in	Ratio MR with Shear / MR	Ratio e/d	Ratio Scaling / Ultimate	Design Load lb.	Factor of Safety
			Scaling of Whitewash in-lb	Yield Point by Observation of Curves in-lb	Ultimate in-lb						
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
B 13	1.48	3.56	8,010	4,850$^\tau$	9,010	1,710	86.0	2.410	88.9	306	8.3
B 14	1.48	3.50	10,720	---	12,720	2,460	93.7	2.360	84.3	416	8.7
B 33	2.90	6.60	31,680	20,200$^\tau$	38,400	2,010	93.5	2.280	82.5	640	9.1
B 34	2.89	1.50	28,590	29,060$^\Delta$	44,900	10,370	82.0	0.519	63.7	3,380	8.9
B 63	5.92	1.56	95,550	90,850$^\Delta$	118,000	12,600	65.1	0.264	81.0	8,530	8.8
B 103	9.96	3.81	324,000	269,000$^\Delta$	379,000	9,980	73.9	0.385	85.0	11,140	8.9
B 13C	1.42	1.31	9,500	7,200$^\Delta$	16,900	9,120	84.0*	0.922	56.5	940	7.6*
B 33D	2.88	1.88	27,000	19,300$^\Delta$	32,400	5,980	64.5	0.650	83.1	2,600	6.7
B 63C	5.92	1.81	123,000	105,000$^\Delta$	151,000	14,150	89.6	0.309	81.5	9,690	8.6

* See discussion

τ From weld strain data by tensometers

Δ By center deflection readings

only taken on Specimens B 13 and B 33 where the average shearing stress on the weld was small. The same type of curve was obtained and the results corresponded closely to the external observations noted above.

2. *Series B*—The test results of this series are divided into Tables II and III. Table II presents the results from Specimens C 62 and C 124. It will be noted that the wing plates are separated from the center plate by a gap of approximately $^{3}/_{64}$ in. (line 2, Table II and Fig. 3). As the load was applied the gap closure was measured with a micrometer, the contact of which was determined by closure of an electrical circuit. The gap closure was found to be proportional to the applied load. It was determined that the weld rotated about the center of its length as long as the gap was open. Upon closure of the gap at one end, rotation took place about that end, and practically the full length of the weld came into use in resisting the applied bending moment, with subsequent great increase in strength.

Early in the tests the wing plates started to scale due to high compressive and shearing stresses in the region of the loading blocks. This yielding became general long before distress was evident in the welds (see Fig. 3). At the final load the welds were fractured a maximum of $^{3}/_{8}$ in. at the ends subjected to tension while only scaling of the whitewash was observed to a depth of about one inch at the compression ends.

Lines 4 to 8, inclusive, of Table II present the observed loads while lines 9 to 12 note the stresses in the members and the welds. Line 9 is calculated as the final load divided by the net shearing area of the wing plates; line 10 as the final load divided by the net bearing area under the loading blocks. Lines 11 and 12 use the values of lines 6 and 8, respectively, and are calculated by the approximate Vector method. Figure 10 exhibits very well

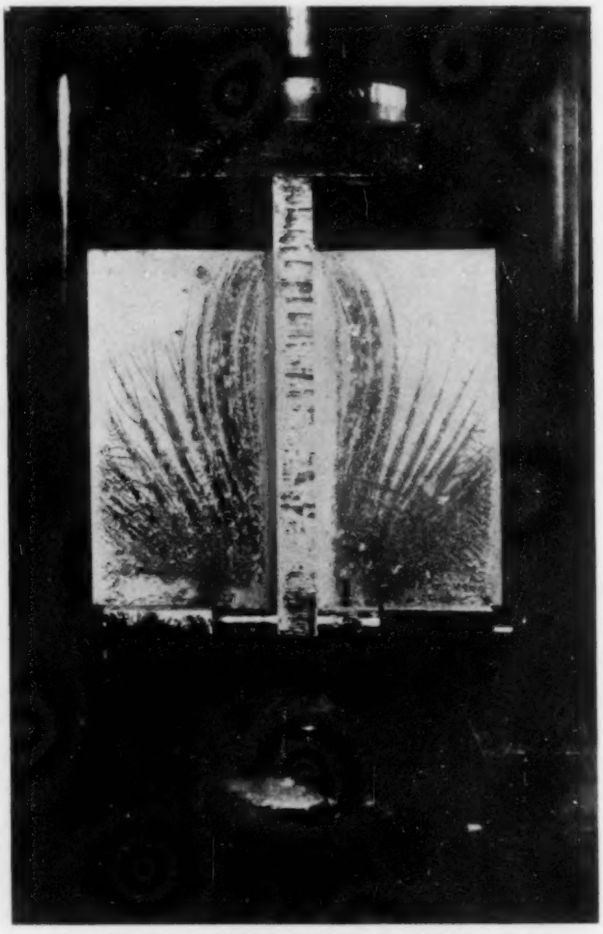


Fig. 10—Specimen C 124 at Total Load of 240,000 Lb.

the yielding due to the combined compression and shear of specimen C 124 at a total load of 240,000 lb.

These specimens indicated the high strengths of welds in combined bending and shear. It became evident that complete fracture of the weld with this design and method of loading was improbable; accordingly the tests were discontinued.

Table III presents the results of the tests on Series B specimens. The first three columns present statistical data. Columns 4, 5 and 6 give the observed bending moments at scaling of the whitewash, yield point from observation of the curves and at the ultimate load. The lever arm used is to the center of the parallel leg of the fillet weld. The use of the distance to the center of gravity of the weld would increase the ultimate bending moment a maximum of five per cent and an average of two per cent with the type of loading used. Column 7 gives the average shear per linear inch based on the total load divided by the total length of weld.

In column 8 the ratio of the resisting moment of column 6 to that of the specimen of similar depth in Series A (Table I, column 5) is calculated, correction being made where required because of the difference in the strength of the weld metal from the two electrodes.

3. *Series C*—The physical properties of the various welding electrodes and deposited weld metal are presented in Tables IV, V and VI. The chemical compositions of the welding electrodes and the deposited metal are given in Table VII.

Typical stress-strain diagrams of the original electrode and of the deposited metal appear in Fig. 11. The dia-

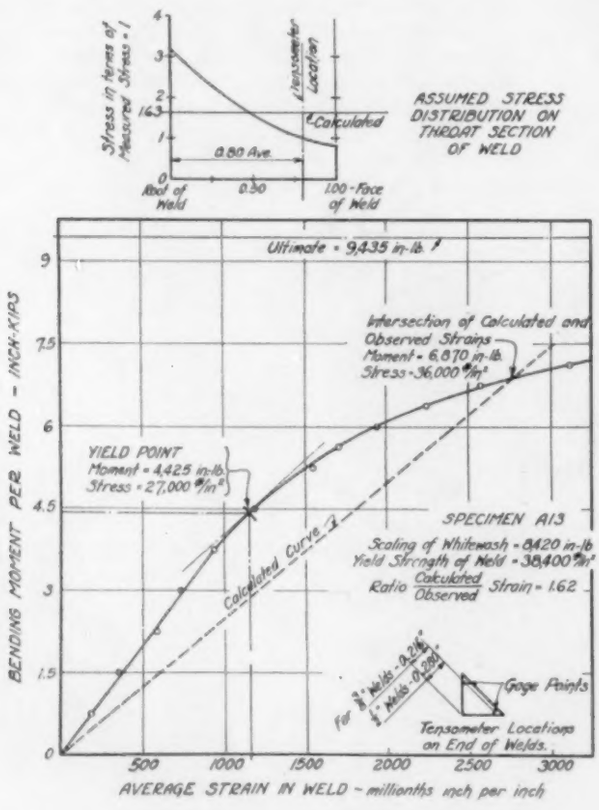

Stress in terms of Measured Stress = 1
Extensometer Location
Calculated
0.80 Ave.
Root of Weld
0.30
1.00 - Face of Weld
ASSUMED STRESS DISTRIBUTION ON THROAT SECTION OF WELD
Ultimate = 9,435 in-lb.
Intersection of Calculated and Observed Strains
Moment = 6,870 in-lb.
Stress = 36,000 #/in²
YIELD POINT
Moment = 4,425 in-lb.
Stress = 27,000 #/in²
SPECIMEN A13
Scaling of Whitewash = 8420 in-lb
Yield Strength of Weld = 38400 #/in²
Ratio Calculated/Observed Strain = 1.62
Calculated Curve 1
Gage Points
Extensometer Locations on End of Welds.
BENDING MOMENT PER WELD - INCH-KIPS
AVERAGE STRAIN IN WELD - millionths inch per inch

FIG. 9 - TYPICAL CURVE - BENDING MOMENT - WELD STRAIN.

gram for the electrode is typical of that of an alloy steel, a definite straight line to a high unit stress followed by a gradual increase in strain in proportion to the stress up to the ultimate. The Johnson limit is high in proportion to the ultimate (75%) and the yield strength 92 per cent of the ultimate. The elongation in two inches is of medium degree, the reduction in area, modulus of elasticity and specific gravity normal in value. The fracture is of the full cup and cone type, showing a finely grained structure.

The stress-strain diagram for the deposited weld metal made with the lightly coated electrode is a straight line to a limit of proportionality, followed by a gradual increase to the ultimate strength, when fracture occurs suddenly with very slight necking. The Johnson limit is approximately 50 per cent of the ultimate strength and on the throat area of the qualification specimens. The average elongation in two inches, approximately six per cent, is somewhat less than is generally shown on the free bend test specimens.

The stress-strain diagram for weld metal deposited from the heavily coated electrodes is similar in nature to that of mild steel. It consists of a straight line, followed by a plateau at which the strain increased without further addition of load, causing a distinct drop of the beam of the testing machine, followed by a steady climb to the ultimate after which considerable necking occurred before fracture. In no case was an upper yield point observed, possibly because of the slow application of the load. The Johnson limit is at 52 per cent and the yield strength at 65 per cent of the ultimate strength. The ductility as indicated by the reduction in area and

TABLE IV - PHYSICAL PROPERTIES OF WELD METAL - ELECTRODE A

	Specimen Number	Johnson Limit lb/sq in	Yield Strength lb/sq in	Ultimate Strength lb/sq in	Equivalent Elongation in 2 in. per cent	Reduction In Area per cent	Modulus of Elasticity lb/sq in	Specific Gravity
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Electrode 3/16" dia	1	64,000	76,800	81,150	17.3	63.0	29,500,000	7.74
	2	64,000	77,500	80,340	16.0	60.3	29,500,000	7.72
	3	63,800	75,600	79,350	--	62.8	29,000,000	7.77
	4	64,000	79,400	81,150	17.3	61.0	29,400,000	--
	Average	64,000	77,300	80,500	16.9	61.8	29,350,000	7.74
3/16" dia Deposited Metal	1	25,500	36,500	49,500	4.6	13.8	24,400,000	7.49
	2	25,500	37,000	51,560	6.7	15.3	24,500,000	7.50
	3	26,200	41,600	59,300	8.7	10.3	24,900,000	7.41
	Average	25,700	38,400	53,450	6.7	13.1	24,600,000	7.47
3/16" dia Deposited Metal*	4	30,500	43,600	52,000	7.3	17.4	25,200,000	7.32
	5	30,500	43,600	59,300	5.3	15.7	24,600,000	7.38
	6	27,800	42,500	57,100	1.3	10.9	24,500,000	7.37
	Average	29,600	43,200	56,100	4.6	14.7	24,800,000	7.36
5/16" dia Deposited Metal	1	26,000	38,200	55,370	5.2	8.3	29,200,000	7.55
	2	27,500	39,200	55,600	---	---	26,200,000	7.47
	3	26,500	39,200	57,800	6.8	11.2	25,400,000	7.53
	4	26,000	37,200	50,500	4.2	15.7	24,700,000	7.52
	Average	26,500	38,400	54,800	5.4	11.7	26,400,000	7.52
1/2" dia Deposited Metal	1	30,800	43,000	54,290	5.7	13.2	27,500,000	7.59
	2	29,500	38,600	51,760	7.7	14.9	26,500,000	7.59
	Average	30,200	40,800	53,000	6.7	14.0	27,000,000	7.59

* Weld deposited using electrode 5/32" diameter and suitable current and voltage

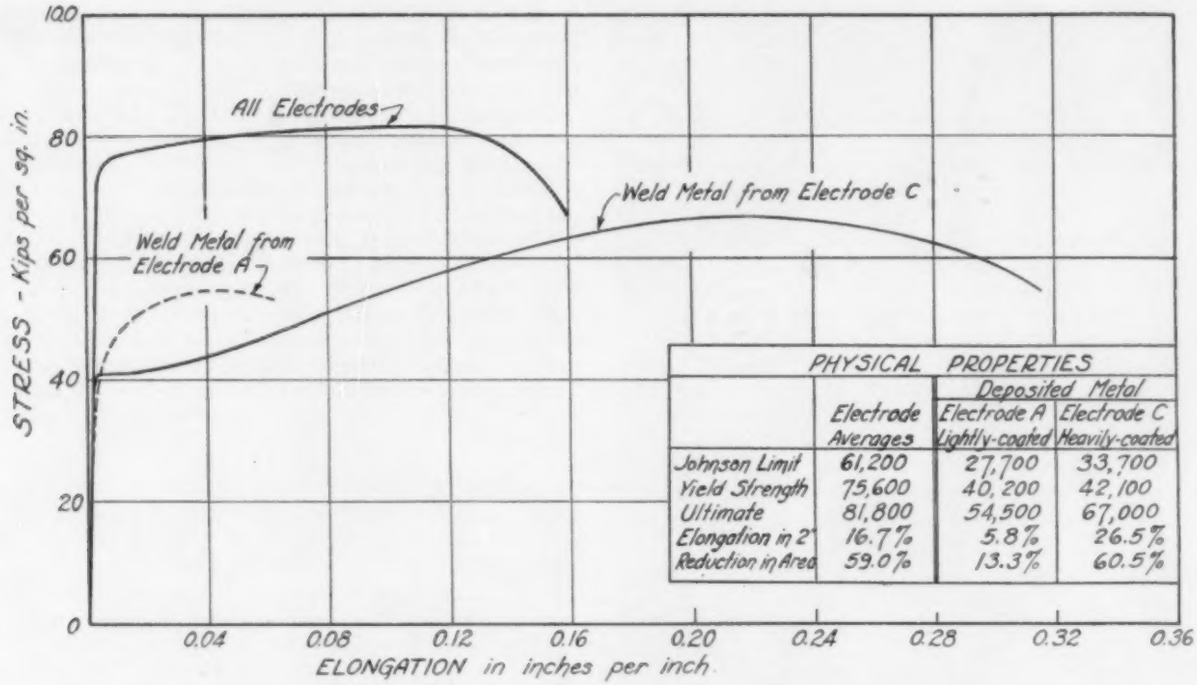
the yield strength 73 per cent of the ultimate strength. The elongation and reduction in area are very small. The modulus of elasticity has been decreased in the case of the single pass weld to 84.2 per cent of that of the original electrode, while at the same time the specific gravity is only 95.8 per cent of the original electrode. When the weld is made in two passes the modulus of elasticity is only reduced to 90 per cent of that of the original metal while the specific gravity drops to 97.2 per cent of the original.

When the weld is deposited in a multiple number of passes, in this case five, so that a $^1/_2$-in. tensile bar can be cut therefrom, the modulus of elasticity reaches 92 per cent of that of the original metal and the specific gravity 98.1 per cent.

The average ultimate strength of the tensile tests is 54,500 lb. per sq. in. comparing with 52,000 lb. per sq. in. the elongation in two inches increased markedly over that shown by the original electrode. The modulus of elasticity and specific gravity show the same values as in the original material. No variation in physical properties was observed beyond ordinary limits with respect to the number of passes by which the weld was deposited.

The average ultimate strength (64,000 lb. per sq. in.) shown by these specimens compares with 70,800 lb. per sq. in. obtained on the throat section of the qualification specimens. Reasons for this discrepancy are not definitely known. The percentage of elongation in two inches compares rather favorably with the results obtained in the free bend test although the variability of repeated results may be criticized. This variability can be condoned when consideration is given to the many variables involved in depositing weld metal.

Figure 12 shows the condition of the $^3/_{16}$-in. tensile



PHYSICAL PROPERTIES		Deposited Metal	
	Electrode Averages	Electrode A Lightly-coated	Electrode C Heavily-coated
Johnson Limit	61,200	27,700	33,700
Yield Strength	75,600	40,200	42,100
Ultimate	81,800	54,500	67,000
Elongation in 2"	16.7%	5.8%	26.5%
Reduction in Area	59.0%	13.3%	60.5%

FIG. 11 - TYPICAL STRESS-STRAIN DIAGRAMS FOR ELECTRODES AND DEPOSITED WELD METAL

bars cut from a weld made with a lightly coated electrode (Electrode A). Although the worst side was photographed, the porosity is quite marked. The highest stress naturally occurred at the most porous section and the fracture occurred at that point as indicated in the broken specimens. Specimens 1, 2 and 3 correspond to those of like number in Table IV. An inspection of the fractured surfaces showed porous patches, blowholes and small inclusions. Inadvertently the solvent used in cleaning the specimens of grease preparatory to making specific gravity determinations formed a sort of dye with the grease which was carried into the interior through the blow-holes on the exterior, staining the exterior and parts of the interior and revealing the extent of the defects, which in some cases covered a considerable area.

The $^{5}/_{16}$-in. diameter specimens showed similar defects both on the surface and throughout the interior although not to so great an extent as did those previously discussed. These observations were verified by the higher specific gravity and modulus of elasticity.

Two $^{1}/_{2}$-in. diameter specimens cut from the multi-pass weld were notable in thel ack of blow-holes appearing on the surface within the gage length. The specific gravity actually proved them to be more dense, but under load they revealed stress concentrations at blowholes very near the surface and the fracture shows a very coarse grain structure, inclusions and porosity.

An effort was made to determine the location at which the fillet structure was most porous and there are indications that this occurs most frequently on the right angle leg near the root of the weld and in the surface layer. However, observations on test specimens most often indicated lack of fusion or porous structure along the parallel leg near the root. The only fact definitely established is that lack of penetration and porosity is in the area about the root of the weld, and porosity in the surface layer of weld metal.

In general the fracture of these specimens may be designated as of the flat cone type with a coarse crystalline

Fig. 12—$^{5}/_{16}$-In. Diameter Tensile Specimens—Lightly Coated Electrode Welds

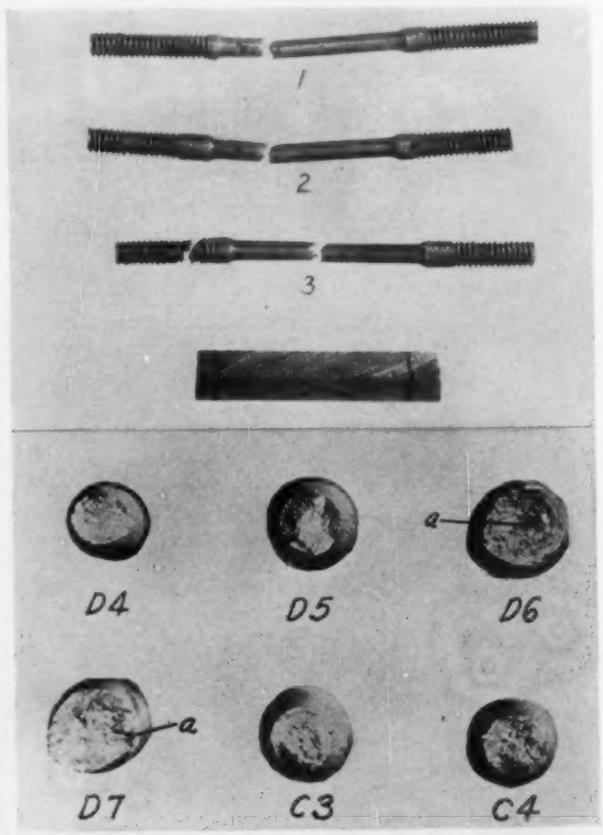


Fig. 13—Cross Sections $^{5}/_{16}$-In. Diameter Tensile Specimens—Heavily Coated Electrode Welds

texture, or of the sheared flat cone type with partly crystalline and partly silky texture. The fractured surface always exhibited the porous structures and some small inclusions even to the naked eye.

Figure 13 illustrates the cross sections of the fractures obtained on the specimens from welds of heavily coated electrodes. The tensile bars themselves were quite satisfactory in appearance, clean looking, solid and finely grained. The fracture was generally full cup and cone, with a fine-grained structure and silky texture as illustrated in D 4 and D 5, and C 3 and C 4. Occasionally the failure was of the sheared cone type, exhibiting a silky texture and slight inclusions. Very probably these inclusions account for the type of fracture rather than the usual reason of eccentric loading conditions.

Specimens D 6 and D 7 show lens-shaped inclusions and blow-holes due to a poor method of depositing the filler metal. Except for this experiment the welding methods followed the general practice of depositing straight-through beads side by side and layer by layer until the desired cross section was obtained or by depositing a straight-through bead at the root followed by the succeeding beads, each layer of which was woven from side to side with a semi-circular motion, the convex side of which was in the direction of the advancing electrode. The importance of proper procedure in depositing the filler metal cannot be better emphasized than by the results of these tests. It is to be noted, however, that very slight effect was shown in the physical results due to this improper manipulation except in those related to ductility as indicated by the percentage of elongation and the reduction in area.

TABLE V - PHYSICAL PROPERTIES OF WELD METAL - ELECTRODE C

	Specimen Number	Johnson Limit lb/sq in	Yield Strength lb/sq in	Ultimate Strength lb/sq in	Equivalent Elongation in 2in. per cent	Reduction In Area per cent	Modulus of Elasticity lb/sq in	Specific Gravity
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Electrode 3/16" dia	1	60,000	73,200	79,890	16.0	55.6	29,200,000	7.75
	2	62,000	75,100	83,440	16.0	55.9	29,400,000	7.80*
	3	63,000	77,200	83,500	14.6	58.4	29,200,000	7.71*
	Average	61,700	75,200	82,300	15.5	56.6	29,300,000	7.75
3/16" dia Deposited Metal	1	36,500	44,300	70,300	22.8	65.7	29,200,000	7.73
	2	32,400	44,300	69,400	22.0	44.4	29,500,000	7.75
	Average	34,500	44,300	69,900	22.4	55.1	29,350,000	7.74
5/16" dia Deposited Metal	1	32,100	40,400	64,500	26.3	65.0	29,200,000	7.79
	2	33,800	39,500	64,300	35.5	66.8	28,700,000	7.78
	Average	33,000	40,000	64,400	30.9	65.9	29,000,000	7.78

* Taken from same electrodes as the tension specimens

Specimen No.1 taken from electrode picked at random

V. Discussion of Results

1. *Series A and B*—(*a*) Effect of Size of Weld. As each depth of specimen was duplicated with $^3/_8$- and $^1/_2$-in. welds the effect of increase in fillet size may be studied under identical conditions. Theoretically a $^1/_2$-in. fillet is 33 per cent stronger than a $^3/_8$-in. fillet and the average results show that this is true in the specimens of Series A under pure bending and in those few cases of Series B where comparison is possible. Where the weld is under transverse bending, the average shear load per inch should be equal to allow for a true comparison. From the results we may safely conclude that the bending resistance increases directly with the increase in fillet size.

(*b*) Effect of Electrode Coating. The ratio of the tensile qualification test values of the heavily coated electrodes C and D to the lightly coated electrode A is 1.37. The ratio of the tensile qualification test values of Electrode A to Electrode B is 0.90. Since the majority of the specimens made with lightly coated electrodes used Electrode A, the results from those specimens on which Electrode B was used will be reduced by ten per cent in order to place all results from the lightly

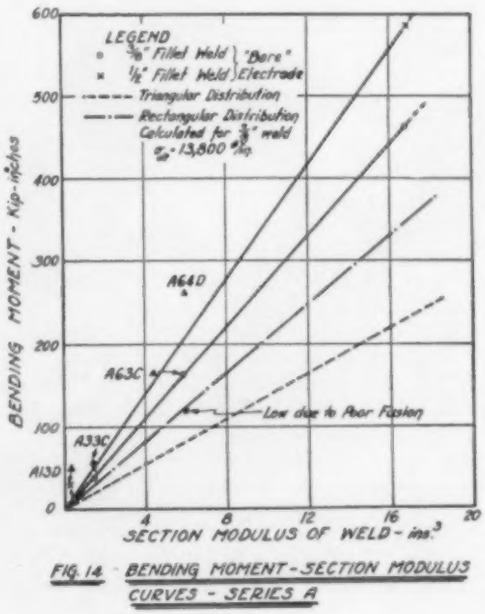


FIG. 14 - BENDING MOMENT - SECTION MODULUS CURVES - SERIES A

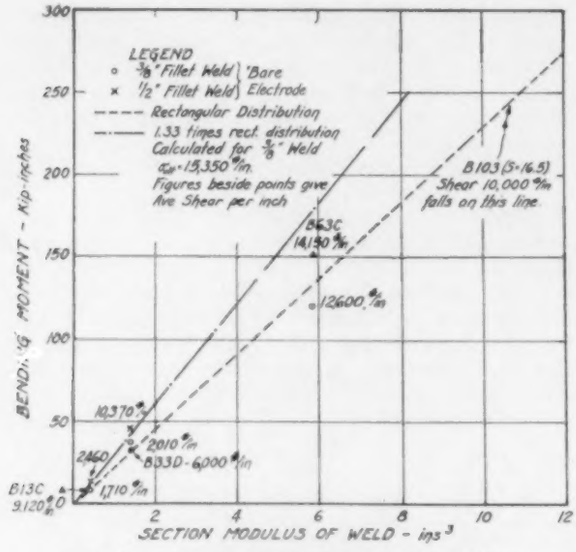

LEGEND
3/8" Fillet Weld } Bare
1/2" Fillet Weld } Electrode
Rectangular Distribution
1.33 times rect. distribution
Calculated for 3/8" Weld
Figures beside points give Ave Shear per inch
B103 (5-16.5) Shear 10,000 #/in falls on this line
B13C 9,120 #/in
BENDING MOMENT - Kip-inches
SECTION MODULUS OF WELD - ins³

FIG. 15 - BENDING MOMENT - SECTION MODULUS CURVES - SERIES B.

determined by bending is 25 per cent greater than that given by the qualification test results in the case of the lightly coated electrode, and only 7 per cent greater in the case of the heavily coated electrode. Including these facts in the calculation it can be shown that the heavily coated electrode increases the strength in bending in the same proportion as is shown by the tensile qualification test results.

(*c*) Figure 14 shows the ultimate bending moments plotted against the section modulus of the specimens of Series A. Those specimens made with Electrode B have been reduced to allow for comparison. The points for $^3/_8$-in. fillet welds fall on a straight line, while the specimens with the half-inch fillet fall on another line 33 per cent above the $^3/_8$-in. fillet specimens. The specimens made with the heavily coated electrode of $^3/_8$-in. fillet size fall midway between the above lines. It will be noted that the results for lightly coated $^3/_8$-in. welds lie considerably above the calculated curves even allowing for full rectangular distribution. The $^1/_2$-in. curve is similarly too steep by about 25 per cent. On the other hand the curve of the heavily coated electrode is very nearly coincident with the calculated assuming

TABLE VI - PHYSICAL PROPERTIES OF WELD METAL - ELECTRODE D

	Specimen Number	Johnson Limit lb/sq in	Yield Strength lb/sq in	Ultimate Strength lb/sq in	Equivalent Elongation in 2 in. per cent	Reduction In Area per cent	Modulus of Elasticity lb/sq in	Specific Gravity
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Electrode 3/16" dia	1	60,000	73,500	82,500	17.3	57.5	28,800,000	7.81
	2	55,000	74,000	82,000	18.6	59.8	28,700,000	7.78
	3	58,500	75,000	82,640	17.3	57.9	29,700,000	7.86
	Average	57,800	74,200	82,380	17.7	58.4	29,100,000	7.82
3/16" dia Deposited Metal	1	26,300	35,700	58,900	26.8	52.0	30,000,000	7.81
	2	41,500	50,600	64,100	24.7	56.4	29,500,000	7.75
	3	28,800	37,800	62,100	23.5	32.1ǂ	29,800,000	7.75
	Average	32,200	41,400	61,700	25.0	54.2	29,800,000	7.77
5/16" dia Deposited Metal	1	36,100	43,900	61,800	33.0	56.8	28,800,000	7.77
	2	34,400	41,000	60,800	28.3	64.8	28,900,000	7.78
	3*	29,000	38,500	59,200	15.2	43.6	28,700,000	7.75
	4°	28,700	39,600	61,300	21.6	35.2	28,900,000	7.79
	5	41,000	42,500	63,470	32.8	53.9	28,500,000	7.76
	6	34,500	42,500	62,520	32.0	57.1	28,500,000	7.75
	Average	36,500	42,500	62,150	31.5	58.2	28,700,000	7.77

ǂ Slight blowholes reduced ductility, omitted in average
* Large blowholes on axis, omitted in average
° Blowholes throughout fractured section, omitted in average

coated electrode welds on a comparable basis. In comparing the heavily coated with the lightly coated specimens a considerable diversity of ratios is apparent from which it seems that although the heavily coated welds are stronger they do not give quite the increase in strength that the qualification specimens indicate. Again in the few specimens that can be compared in Series B the results at equal average shearing loads per inch must be used and these do show an increase in favor of the heavily coated electrode, but slightly less than the tensile qualification test results indicate. While here the ratio of the qualification test results is taken as the criterion, the ratio of the calculated ultimate stress as given in column 7 of Table I may be used. This ratio is only 1.19, since the calculated ultimate strength as rectangular distribution. This is typical of the action of comparatively brittle and very ductile materials and the phenomena is explained in texts on the resistance of materials.[2]

In Fig. 15 the ultimate moment is again plotted against the section modulus. The figures beside each plotted point are the average shear per inch of weld at the ultimate load. The calculated curve is that for a $^3/_8$-in. weld, assuming rectangular distribution. It will be noted that even though the average shear in the weld was as high as 82 per cent of the tensile qualification weld strength, the resultant bending strength did not fall below that of rectangular distribution, excluding shear, based on the tensile qualification strength. This is because of the large ratio between the modulus of rupture

and the ultimate strength. In the case of the heavily coated electrodes giving more ductile welds, the ratio is not so large and the points fall below the calculated rectangular distribution stress, especially where the average shearing load is high.

(*d*) Returning to Series A, and Fig. 9. Photoelastic investigation[3] of stress distribution in the weld shows that the direction of one of the principal stresses is almost at right angles to the throat section. Hence the tensometers, since they were placed parallel to the hypotenuse, should measure the magnitude of the strain due to this stress. The same investigation showed that the stress across the throat was almost constant for about half the distance from the edge to the root and then increased rapidly to a magnitude of about $2^1/_2$ to 3 times as much as that at the edge. The tensometers were placed about 80 per cent of the distance from the root of the weld and the average ratio between computed and measured strains was 1.63. If we now assume a parabolic variation of strain and hence stress along the throat section so that there is a balance between the average rectangular area and that bounded by the parabola which has its axis slightly beyond the boundary of the section, the maximum stress at the root will be about twice (1.96) the average calculated stress. This corresponds to a ratio of 2.44 shown in the photoelastic investigation. The fact that the strain at the socalled yield point of the weld corresponds to that at the Johnson limit of the weld metal tends to show that the stress-strain curves of the weld metal taken either from a tension specimen (Series C) or from the weld in place are similar. The strain in the weld increases until the yield strength is reached, at which point there is a general correspondence between the yield strength, the scaling of the whitewash on the surface of the weld and the calculated strain. By this time the stress condition across the weld section must be almost uniform for the stress now increases very slowly compared to the strain increments.

While the data are not complete the following facts below the proportional limit of the weld metal seem to be indicated:

(1) That the strain at the root of the weld is about three times that at the other end of the throat section and that this strain is also about twice the average strain on the weld.

(2) That the weld stress is proportional to the applied moment up to the Johnson limit of the weld metal.

(3) That scaling of the whitewash on the surface of the weld occurs when the yield strength of the weld metal is reached and at this point the stress distribution over the weld cross section is practically uniform.

(4) That the ordinary design formulas will give the average stress condition in the weld for stresses up to the yield strength of the weld metal.

(*e*) It was pointed out that the specimens made with lightly coated electrodes always fractured near the throat section while those welded with heavily coated electrodes had the plane of failure at a very flat angle to the main plate. These same types of failure are common in the end fillet weld qualification tests where the welds are under tension. The photoelastic analysis shows, and it is somewhat generally conceded, that the stress along the right angle leg of the weld is almost pure tension, and that across the throat section or very near to it is also in tension, while that along the parallel leg is at a maximum in shear. This shear plane is 1.41 times as great in area as that of the throat section. Since the ultimate shearing stress is generally eighty per cent of the tensile ultimate, it is easily seen that failure should occur along the throat plane. For the lightly coated electrode this shearing ultimate stress would be about 42,000 lb. per sq. in. Furthermore should the ratio of the shearing ultimate to the tension ultimate decrease in the case of the heavily coated electrodes, and should this ratio then be less than seventy per cent, failure would be due to shear and would be along the plane of the main plate or at a flat angle thereto.

TABLE VII - CHEMICAL ANALYSIS OF ELECTRODES AND DEPOSITED METAL

Element	Electrode A		Electrode C		Electrode D	
	Electrode per cent	Deposited Metal per cent	Electrode per cent	Deposited Metal per cent	Electrode per cent	Deposited Metal per cent
C	0.16	0.15	0.13	0.11	0.14	0.08
Mn	0.42	0.25	0.50	0.62	0.51	0.31
P	0.017	0.014	0.012	0.015	0.015	0.020
S	0.022	0.030	0.023	0.023	0.029	0.030
Si	0.01	trace	0.01	0.28	---	0.10
Mo	none	none	none	none	---	0.02
Ni	--	--	--	none	---	0.05
Cr	--	--	--	none	---	none
Cu	--	--	--	0.12	---	0.05

The tensile tests give an average ultimate for Electrode D of 61,600 lb. per sq. in. and including Electrode C the grand average is 63,830 lb. per sq. in. The shearing ultimate should therefore be about 49,300 to 51,200 lb. per sq. in. The qualification specimens showed an average ultimate on the throat section of the weld of 70,800 lb. per sq. in. although the line of fracture was at a flat angle to the main plate. Since the ratio of the shearing ultimate as determined above to the ultimate as given by the qualification specimens is 0.69 to 0.71 it is possible that this explanation accounts for the failure of heavily coated electrode welds. The ratio of 0.7 between the ultimate strengths in shear and in tension was reported by Professor H. Dustin.[6] Whether it accounts for it or not, the fact remains that welds with heavily coated electrodes always exhibit this type of fracture as distinctive from those exhibited by a lightly coated electrode weld.

(*f*) Let us now consider the method used in calculating stresses in the welds in Series B. If we consider

formula (3) and consider only the stress set up by bending, the stress σ will then be proportional to $\frac{P}{d}$ and a factor $\frac{6e}{d} = K_1$. The value of K_1 will then vary linearly with the ratio of $\frac{e}{d}$. This is plotted on Fig. 16.

Considering the effect of shear the factor K_2 becomes $\frac{\sqrt{36e^2 + d^2}}{d}$ and the relation between this factor and $\frac{e}{d}$ is also plotted and labeled Vector Method. As stated previously this method is merely approximate. It will be noted that at small values of $\frac{e}{d}$ there is a considerable increase in the value of K_2 over K_1 and that for greater values the curve approaches the curve of pure bending asymptotically.

If the principal stress is determined by the general formula (4), K_3 is represented by:

$$K_3 = \frac{3e}{d} + \frac{\sqrt{9e^2 + d^2}}{d}$$

and the relation between K_3 and $\frac{e}{d}$ may be plotted. This departs still further from the curve of pure bending but again approaches it asymptotically. Above $\frac{e}{d} = 1.0$ the curves as determined by the Vector and Principal Stress Methods become almost coincident.

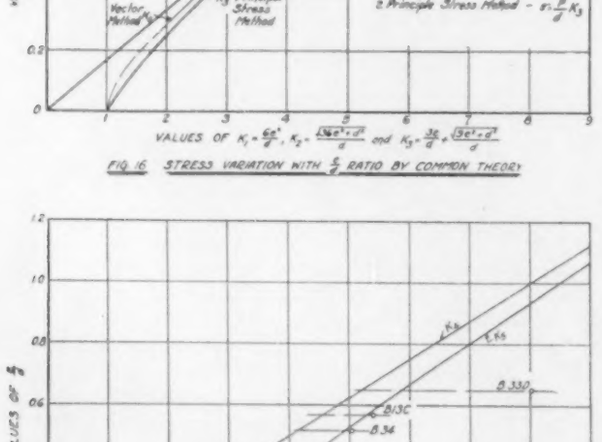

VALUES OF e/d
Vector Method
Principal Stress Method
To Calculate Weld Stress σ
Bending without Shear σ = P/d K1
Bending with Shear
1 Approximate (Vector) Method σ = P/d K2
2 Principle Stress Method σ = P/d K3
VALUES OF K1 = 6e/d, K2 = √(36e²+d²)/d and K3 = 3e/d + √(9e²+d²)/d

FIG. 16 STRESS VARIATION WITH $\frac{e}{d}$ RATIO BY COMMON THEORY

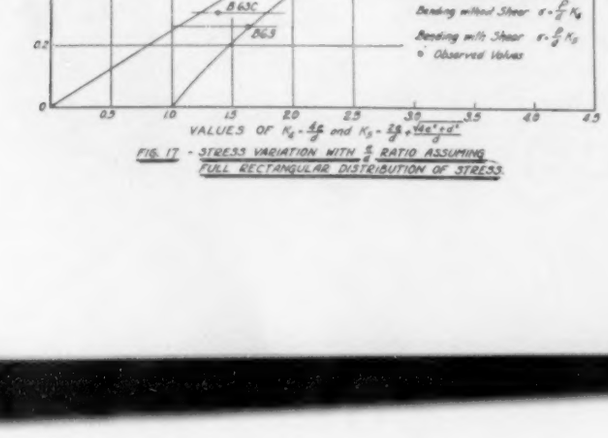


FIG. 17 - STRESS VARIATION WITH $\frac{e}{d}$ RATIO ASSUMING FULL RECTANGULAR DISTRIBUTION OF STRESS.

If, instead of considering the triangular distribution, we plot curves on the basis of rectangular distribution of stress, there results Fig. 17. K_4 for pure bending then is equal to $\frac{4e}{d}$ while $K_5 = \frac{2e}{d} + \frac{\sqrt{4e^2 + d^2}}{d}$ using the Principal Stress Method. On this figure too are plotted the $\frac{e}{d}$ ratios applicable to the specimens in this investigation and the ratio of the strength which they developed in shear and bending to that developed in pure bending. Comparison is then made with the ratio of the calculated strengths. It will be noted that the observed points fall very close to the curve determined by the Principal Stress Method.

The point for B 33D falls far to one side of this curve, which is probably due to the fact that the loading blocks on A 33C tilted, decreasing the lever arm and hence increasing the observed load at failure. Since the nominal lever arm was used in calculating the ultimate bending moment, this would give an abnormally high bending moment. This would account for the low ratio of B 33D to A 33C which is the basis for the plotting of the points on Fig. 17.

The point for B 63C is slightly high probably due to poor metal along the toe of the welds, which evidently lacked complete fusion with the base metal.

The loading blocks used with B 13C tilted a measurable amount thus shortening the lever arm. Calculations were based on the assumption that one of the lever arms was shortened $^7/_8$ in. and the other $^1/_2$ in. giving net lever arms of 0.43 and 0.81 in., respectively. Since failure occurred on the welds subjected to the 0.81-in. lever arm, the e/d ratio was calculated as 0.57. The ratio of the ultimate moments of B 13C to A 13D is then 92.8 per cent while the calculated ratio is 86.0 per cent. The calculated moment is very sensitive to variations in load distribution.

In Specimens B 13, B 14 and B 33 the effect of the shearing stress should be negligible since the e/d ratio is above two. The ultimate bending moments should be almost equal to those of their companion specimens in Series A. That they do not thus agree is probably due to variations in the deposited welds. It is generally considered that variations of plus or minus ten per cent of the average in the results of weld tests are quite reasonable. The majority of the results in this investigation fall well within this range and are generally consistent.

Here again the results tend to indicate that full rectangular distribution of stress is reached in the welds at failure and that the ultimate strength may be based on this method of calculation.

The curves show the very small effect that a low average shearing stress has upon the strength of the weld. The bending strength will not be decreased more than ten per cent as long as the lever arm of the load is at least twice the length of the weld. For shorter lever arms in relation to weld length it would be better to consider the effect of shear. There is also indicated the small difference in the results whether based on the Vector Method or Principal Stress Method: but the Principal Stress Method gives more conservative and probably more accurate values.

(g) Turning again to Table I, the ratio of the average modulus of rupture to the ultimate strength of the qualification specimens is 1.87 for both $^3/_8$ and $^1/_2$-in. lightly coated electrode fillet welds. The heavily coated electrode welds show a ratio of only 1.61. From these figures the factor of safety can be calculated using weld stresses of 3000, 4000 and 3750 lb. per lin. in. for $^3/_8$, $^1/_2$

"bare wire" and $^3/_8$-in. heavily coated electrode welds, respectively. The factors of safety, column 12, range from 6.5 to 10.3 including all specimens. Discarding A 34-1, A 63-1 and A 64 with factors between 6 and 7 because they are definitely low due to poor fusion in the weld, the lowest factor is 7.5.

Consider Table III, columns 11 and 12. Here calculations based on the Principal Stress Method give factors of safety from 6.7 to 9.1. Using the Vector Method the factors of safety would be slightly less.

(*h*) It has been suggested that some variation in results is reasonable and as far as possible the causes of these variations have been discussed. The strains in the weld measured by the tensometers showed particularly well any lack of fusion in the weld long before failure. These observations were omitted in working up the average bending moment-weld strain curves.

A possible cause of variation is found in the secondary stresses to which the weld was subjected, the consideration of which has been entirely omitted in the discussion. One of these secondary stresses is that caused by the longitudinal buckling of the compression side of the splice plate due to the eccentric compression load to which it was subjected. This phenomenon was quite noticeable in certain specimens, notably A 64D, A 63-2, A 103 and A 104. The result was a prying action at the root of the weld and may account for the scaling of the weld at the compression end before scaling occurred at the tension end. In addition there are the secondary stresses due to the necessity for the stress to follow a broken path and the influence of localized stresses due to the loading blocks, especially in Series B. These probably have only a small effect on the total strength of the weld.

2. *Specimens C 62 and C 124*—The total angle of rotation of the welds on these two specimens was 0.0125 and 0.0075 radian, respectively. At this point the calculated maximum weld stress was approximately equal to the ultimate strength shown by the tensile tests (54,500 lb. per sq. in.), and small cracks were noted in the tension ends of the welds.

The plates were displaced due to the gouging action of the loading blocks $^5/_{16}$ and $^3/_{16}$ in., respectively, at the final load. It is inconceivable that this great distortion of the wing plates could occur without detrimentally affecting the weld strength.

The ratio of the thickness of the wing plates to the total throat section of the welds was, respectively, 0.93 and 1.32. In both these tests yielding occurred in the plates before any distress was evidenced by the welds themselves.

3. *Comments on Series C Specimens*—(*a*) The considerable porosity manifested in the lightly coated electrode welds is not unusual and is well presented in "Metallurgical Data on Fusion Weld Joints" by A. J. Moses, *Journal American Welding Society*, Vol. 14, No. 4, April 1935. As the number of passes increases the porosity is reduced, probably because the subsequent pass removes the porous top layer and replaces it with denser metal. With the decrease in porosity, the modulus of elasticity increases, there is a slight improvement in ductility and a slightly higher Johnson limit. The most interesting phenomena is the relation of the modulus of elasticity to the specific gravity of the specimen. This is as follows: The ratio of the moduli of elasticity of the deposited weld metal and the electrode varies directly as the fourth power of the ratio of their specific gravities. No explanation is offered for this relation.

The specimens of each group and as a whole give remarkably uniform results considering the inhomogeneity of the metal. The decrease in the physical properties of the deposited weld metal compared to those of the original electrode amounted to 33 per cent in ultimate strength, 66 per cent in elongation in 2 in. and 78 per cent in reduction in area.

(*b*) With the welds from heavily coated electrodes the results are different. The specific gravity and modulus of elasticity remained constant; the ultimate strength only showed a decrease of 25 per cent in the extreme case of Electrode D, compared with the original electrode properties. Electrode C only showed a loss of 18.4 per cent of the original electrode strength. The percentage elongation was double that of the original electrode while the reduction in area was about constant at approximately 58 per cent.

Both electrodes showed weld throat stresses in the qualification tests of high order, 71,000 lb. per sq. in. Electrode C approached this with an average of 67,200 lb. per sq. in. in the tensile tests, but Electrode D persistently showed ultimates which averaged 61,600 lb. per sq. in. This is the reverse of the performance of the lightly coated electrode welds and no explanation is offered. The tests were sufficiently conclusive and of uniform results to prove the facts as stated above.

VI. Summary and Conclusions

Based upon the observed behavior of the specimens and subject to the limitations imposed by them, the following summary and conclusions are presented.

1. The bending tests showed that the present design methods are very conservative and give a factor of safety of at least 7 when based on the ultimate strength of the weld.

2. The ordinary design formulas will give the stress condition in the weld for stresses up to the yield strength of the material. The principal stress method for computing combined stress is found to be more conservative and probably more exact.

3. The stress condition in the weld may be summarized as follows:

(*a*) The weld stress is proportional to the applied load up to the Johnson limit of the weld material.

(*b*) The strain at the root of the weld is about twice the average strain and about three times that at the free boundary of the weld.

(*c*) The stress is practically uniformly distributed over the weld cross section at the loading which causes scaling of the whitewash on the surface of the weld.

4. Despite the low ductility of welds made with the lightly coated electrode, the ductility is sufficient to allow for the development of the full rectangular distribution of stress along the length of the weld.

5. Using this rectangular distribution of stress, the full resisting moment based upon the ultimate strength of the qualification tests is developed even though the average shearing stress is as great as eighty per cent of this ultimate strength.

6. The full theoretical increase in strength is observed in the comparison of $^1/_2$-in. fillets and $^3/_8$-in. fillets in both the lightly coated and heavily coated electrodes.

7. The use of heavily coated electrodes gives some increase in strength, approximately in the ratio of their tensile ultimate strengths, rather than in the ratio of the qualification test strengths.

8. Welds of lightly coated electrodes are rather porous despite their good external appearance and maintenance of the prescribed ultimate strength. This porosity decreases the specific gravity and the modulus of elasticity in a rather unusual ratio.

9. Multilayer welds with lightly coated electrodes tended to become more compact, with resultant increase in specific gravity, modulus of elasticity and ductility.

10. Heavily coated electrodes gave physical properties equal to or exceeding in all the items tested the usual grades of structural steel.

11. The tests indicated the necessity of determining the shearing modulus and shearing strengths of weld metal from both the lightly coated and heavily coated electrodes.

[1] Inge Lyse and N. G. Schreiner, "An Investigation of Welded Seat Angle Connections," *Journal, A. W. S.*, February 1935, Vol. 14, No. 2.
[2] F. B. Seely, "Resistance of Materials," pp. 114–115.
[3] A. G. Solakian, "Stresses in Transverse Fillet Welds by Photoelastic Methods," *Journal, A. W. S.*, February 1934, Vol. 13, No. 2.
[4] A. J. Moses, "Metallurgical Data on Fusion Weld Joints," *Journal, A. W. S.*, April 1935, Vol. 14, No. 4.
[5] J. C. Hodge, "Chemistry of Low-Carbon Metal-Arc Weld Metals," *Journal, A. W. S.*, October 1932, Vol. 11, No. 10.
[6] H. Dustin, "Metal Arc Welding," *Journal, A. W. S.*, September 1928, Vol. 7, No. 9.
[7] H. Dustin, "Fundamental Principles of Arc Welding," *Arc Welding*, edited by E. P. Hulse, pp. 182–223.
[8] H. M. Priest, "Practical Design of Welded Steel Structures," *Journal, A. W. S.*, August 1933, Vol. 12, No. 8.
[9] C. D. Jensen, "Stresses in Fillet Welds," *Journal, A. W. S.*, February 1934, Vol. 13, No. 2.
[10] C. H. Jennings, "Computed Fillet Weld Stresses," *Welding*, Vol. 2, No. 2, February 1931, and *Journal, A. W. S.*, July 1930, Vol. 9, No. 7.
[11] H. Neese, "Welding of Structural Steel," *Stahlbau*, Vol. 2, No. 14, July 12, 1929, pp. 161–167.
[12] R. L. Templin, "Tension Testing of Materials," *Metal Progress*, February 1935, pp. 29–32.
[13] Coker and Filon, "Photoelasticity," pp. 685–688.
[14] G. F. Swain, "Strength of Materials," pp. 232–239.
[15] Johnson, "Materials of Construction," 7th ed., pp. 28, 712, 725.
[16] S. Timoshenko, "Strength of Materials," Vol. 1, p. 237.
[17] Merriman and Wiggin, "American Civil Engineers Handbook," pp. 587, 667.

Bridge Welding—A Review of the Literature†

By F. H. FRANKLAND*

A STUDY of the literature relating to the use of welding in the construction of bridges shows that, although we may consider the inception of the welded bridge as dating from about 1922, much that was known of welding technology, even four or five years ago, has been superseded and is out of date. This rapid development therefore makes it imperative to exercise sound engineering judgment and clear thinking when evaluating the information available. The fundamental principles of welding are such that there are no precedents that can be adopted from other forms of construction, and it therefore follows that creative originality and inventive genius are necessary in the engineer engaged in the design and construction of welded bridges.

New equipment, incorporating in many cases very considerable improvements, has been rapidly developed during the past few years, and in addition new processes have come into being and far-reaching improvements have been made in filler metal materials. Also changing points of view have resulted from the large volume of scientific research that has recently been carried on. Professor Bardtke of Germany says: "It is no exaggeration to say that in the field of engineering technology the greatest single development which is taking place today is in 'Welding.' "

In the preparation of a summary and abstracts of published data relating to the use of welding in bridge construction, by J. M. Frankland, July 1935, for the American Welding Society's Committee to Study the Design and Construction of Welded Highway and Railway Bridges, a mass of papers and books were studied and the items chosen for abstracting were confined to those that were considered properly representative of the latest developments influencing welded bridge construction. This document has been used as the basis for this paper and the bibliography and abstracts incorporated form the appendix which will appear in printed form as part of this paper; they cover sixty-one main items, dating from 1926 to September 1935. Among these items, listed as one, was Bulletin No. 3, dated June 1935, of the International Association for Bridge and Structural Engineering, containing seven separate papers, and the Symposium on the welding of iron and steel held at London in May 1935, under the auspices of the Iron and Steel Institute of Great Britain, which included a large number of papers covering the entire field of welding. Of the entire collection of papers presented at this symposium thirty-one were listed as of particular interest in bridge welding. These papers may be considered as the most comprehensive and up-to-date discussion of the entire field of welding, and a study of the thirty-one papers selected for comment comprise one of the most valuable additions to the literature relating to bridge welding.

A study of the literature referred to reveals that most of the problems relating to local structural matters and of material are in reality old questions which must be answered for all types of construction. Fifty years of experience with steel structures has taught us how to ask pertinent questions and new fabricating methods must be subjected to more searching examination than the old. Such questions concern the stress distribution in welds, connections and members, internal stresses, impact strength and strength under repeated loading of welds and connections, the effect of plasticity upon the local strength, and the best ways of breaking up a continuous structure into parts convenient for economical shop fabrication and field erection.

Many experimental studies have been made of the stress distribution in welded joints under load. Unfortunately most of these investigations have been carried out without adequate theoretical analysis of the problem or of the data secured. The stresses are always at least two-dimensional and are usually three-dimensional in the regions of greatest intensity, as at the ends of fillets. The strain-gage reading multiplied by a constant does not give the corresponding stress in such circumstances, as many investigators light-heartedly assume. It is well to realize that the usefulness of photoelastic studies is strictly limited, because the highest stresses occur most often in a region of three-dimensional stress which the photoelastic technique is necessarily unable to analyze. However, the results may frequently be of interest in presenting an approximate and qualitative picture. Certain phases of this picture are discussed by Gottfeldt in his paper published in *die Bauingenieur* in 1934 and described in item 54 of the appended abstracts. Coker describes, in item 34 of the abstracts, the results of two-dimensional stress distribution in fillet welds as obtained by photoelastic methods, showing the stress concentrations at the edge of the bead and at discontinuities in the interior of the joint due to unsatisfactory root penetration and to unwelded faying surfaces as in a lap joint. The most definite result on stress distribution in welds is the analysis of the longitudinal shear averaged over the cross section of a side fillet weld. Here the shear distribution is parabolic, falling to a minimum near mid-length in much the same way as the shearing force is distributed over a line of rivets. The greatest shear occurs at the ends of the welds, and, beyond a certain minimum length, appears to be practically independent of the weld.

During welding the thermal expansion of the deposited and base metal causes permanent deformation of the still plastic hot metal. As the weld cools, the thermal strains disappear and the resulting reverse deformation sets up exceedingly large internal stresses both in weld and base metal. Bollenrath and Mathar (see abstract items Nos. 46 and 43, respectively) have investigated these stresses by a method devised by Mathar which appears more promising than any other. The method consists of drilling a hole in the stressed plate and measuring the deformation of the hole with special apparatus.

Among the papers at the London Symposium that are of particular interest as indicating the important researches recently carried on are those of G. Roberts of Dorman, Long & Co. (60*e*) reporting on tests of static strength of butt welds in two-inch plate wherein it was

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demonstrated that the better type of joints developed practically the full strength of the plate; that of Prof. H. J. Gough of the National Physical Laboratory (60*g*), detailing the welding research program of the Steel Structures Research Committee of the Department of Scientific and Industrial Research (England); that of D. Arvidsson (60*i*), giving a detailed account of the design and all-welded construction of the Pålsund bridge in Stockholm; that of G. Ellson (60*k*), of the Southern Railway of England, reporting on experiments to ascertain the effects of strengthening girders by welding; that of Ros and Eichinger, Zurich (60*l*), on static and dynamic strength of welded joints, containing the results of much original research on this subject. This report is most complete and valuable. The paper by Benson and Allison of Metropolitan-Vickers Co. (60*n*), should also be mentioned. It describes experiments to determine the best conditions for stress-relieving by annealing. S. Bryla, Warsaw (60*s*), reports on the results of tests with rolled beams reinforced with welded plates; and O. Bondy of London (60*u*), presents a paper on the relations between the design and fatigue strength of welded structural joints. W. T. Everall of India (60*aa*), reports on experiments carried out on riveted joints strengthened by arc welding and Colam and Watson also of India (60*ee*), give the results of experiments to ascertain the permanent, and consequent change in, stress distribution by welding to a stressed member. In addition to these papers just referred to, there should be mentioned the report of Professors Young and Jackson, University of Toronto (55), on the rigidity of welded and riveted joints; that of G. A. Nikolaieff (42), describing the experimental investigations and experience with the construction of welded bridges in Russia; and the papers of Norman G. Schreiner, Lehigh University (61), presenting the results of tests of fillet welds under loading conditions to which they are commonly subjected.

All these papers relate to recently completed research, and my purpose in specially referring to them is to show the vast amount of significant research now being carried on in various countries.

We find ourselves in an unusual situation wherein the actual use of welding in bridge work today has created an extraordinary and urgent demand for data governing design and construction. The importance of the work of the Bridge Committee of the AMERICAN WELDING SOCIETY in developing a standard specification for design and construction cannot be over-emphasized, and their forthcoming specification is therefore of the greatest significance.

Until recently the greatest contributor to the engineering research in connection with welded bridges has been Germany. This was largely due to the fact that two pressing engineering problems involving the interests of the producer of materials, the engineer and the large consumer developed simultaneously; these were the questions of high-strength structural steels and of welded construction. Steel producers, state and university testing laboratories, the German State Railways, the shipyards and the government combined to attack these problems by coordinated research, with fruitful results. Much of this work is of such a character that it would hardly have been undertaken by isolated effort, such as the work on the strength of riveted and welded joints under repeated loading for which expensive special equipment was required. However, engineering research in the problems of welding is spreading rapidly to other countries, particularly the United States and Great Britain. A vast amount of welding research has been carried out in this country by industrial concerns that related to some particular or specialized problem—the results of such work, considered in the light of application to the general problems of bridge welding, were for the most part fragmentary and confined within narrow limits.

Welding as applied to bridges and other similar dynamically loaded structures involves particular problems that originate partly from the nature of such structures as compared to buildings. Bridges carry repeated loads and impact loads, which occur only in a comparatively limited degree in buildings. Welding introduces special problems of its own in bridge design and construction, and these problems may be divided into two groups: first, the problems of materials and the detailed design of members and connections, and, second, the problems which arise from the use of the types of structures and structural forms to which welding may be well adapted. It is becoming increasingly evident that welding is not merely another way of joining metals, but that it calls for special forms and types of construction for its special advantages to be realized to the fullest.

In the past many experimental studies of the stress distribution in welded joints under load have been carried out. Unfortunately most of these investigations have been made without adequate theoretical analysis of the problem or of the resulting data. It is therefore of prime importance that great care and judgment be exercised when examining the results of welding research, so that false conclusions may be avoided.

It may be well to repeat the quotation from Francis Bacon that appeared on the flyleaf of the Report of the Structural Steel Welding Committee—"If a man will begin with certainties, he shall end in doubts; but if he will be content to begin in doubts, he may end in certainties."

The main obstacles that welding had to overcome in the early stages of its development were to prove that the deposited metal was sound and possessed good physical properties and that the work of welders could be relied upon. Ample assurance of both these points has been furnished, an outstanding contribution being the 1931 Report of the Structural Steel Welding Committee of the American Bureau of Welding and cooperating groups. The manufacturers of welding supplies and equipment have made great advances, especially with the development of coated welding wire, the use of which is rapidly becoming general.

The popularity of welding is due to economic rather than technical causes, and it has been necessary for welding technology to undergo lively development to keep pace with the practical application. Bold steps have been taken in construction which have not always received the full approval of subsequent confirmation. Specifications must therefore carry the double responsibility of preventing unsound practice, due to uninformed use, and avoiding the imposition of hampering restrictions on a technique which is developing with extraordinary rapidity.

Appendix

Abstracts of Literature Relating to Welded Bridge Construction

1926

1. A. G. Bissell, "Electric Arc Welding in the Manufacture of Structural Steel," *Jour. A. W. S.*, Sept. 1926, pp. 24–34.

The author describes static and dynamic tests to compare the strength of welded and riveted connections. The impact and vibration tests of beam-to-column connections in shear are of particular interest. The results indicate the high strength of the welded connections under both static and dynamic loading.

1927

2. "Report of Structural Steel Welding Committee on Survey of Existing Data," *Jour. A. W. S.*, Nov. 1927, pp. 11–14.

Tables summarize the existing test results (through 1926) on the strength of welded joints. A bibliography lists published and unpublished data not conveniently summarized in the tables. All references are to American work.

1928

3. "Large Factory Structure Built by Arc Welding," *Eng. News-Record*, **100,** 766–769 (1928).

Description of the arc-welded building for the Philadelphia plant of the General Electric Company. Roof trusses and crane runway details are of interest. The design is said to save 12 to 15 per cent of the weight of steel in a comparable riveted structure.

4. F. P. McKibben, "A List of Welded Structures," *Jour. A. W. S.*, Oct. 1928, pp. 18–21.

5. G. D. Fish, "Arc-Welded Buildings and Bridges," *Jour. A. W. S.*, June 1928, pp. 54–58.

Description of several welded structures in the design of which the author had participated. They include the Sharon building, the Turtle Creek bridge and the Chicopee Falls bridge. It is stated that the use of continuous beams and columns reduced the total weight of steel in the Sharon building by 10 per cent. (See ref. 6.)

6. A. G. Bissell, "An Arc-Welded Railroad Bridge," *Jour. A. W. S.*, April 1928, pp. 42–46.

Description of a plate-girder railroad bridge of 53-foot span at Turtle Creek, Pa. The bridge was completed in 1927. To ensure continuity of stringers, a horizontal slit was cut in the webs of the floor beams to take a strap connecting the top flanges of the stringers.

1929

7. G. D. Fish, "Specifications for Arc-Welded Connections in Bridges," *Eng. News-Record*, **103,** 292–297 (1929).

A definite specification for bridge welding is offered by the author. The article also contains a discussion of the types of welds and of the manner in which welds are stressed in different types of connections. A formula is given for the design of joints subjected to dynamic (repeated) loading, the formula being similar to the one used in Part II of the German welding specifications.

1930

8. S. Bryla, "First Arc-Welded Bridge in Europe," *Jour. A. W. S.*, May 1930, pp. 71–75. Also *Eng. News-Record*, **104,** 644–645 (1930).

Description of the truss bridge at Lowicz, Poland, of 88-foot span. The stringers were connected to the webs of the floor beams at mid-height of the latter, and plate stiffeners run from top and bottom stringer flanges to the web and flanges of the floor beam. The resulting continuity obtained in the stringers is said to have saved 12 per cent of the steel in the floor system.

9. "Bridges Welded in Field on Australian Railway," *Jour. A. W. S.*, Jan. 1930, pp. 16–17.

Note trough-plate floor made of channels welded toe to toe. The channels were cut to length in the field and welded directly to the plate girder webs.

10. Schaper, "The First Welded Railway Bridge for Main-Track Service," *Bautechnik*, **8,** 323–325 (1930).

The article describes a 33-foot span plate girder bridge on the German State Railways. The bridge was all welded. Inspection by X-rays in the field and proof tests by static and dynamic loading are described.

1931

11. "Report of Structural Steel Welding Committee of the American Bureau of Welding."

A statistical survey of the reliability of welds and welders and of the static strength of a large variety of welded joints.

12. K. Baumbartel, "Study of the Influence of Covered Electrodes on the Tensile Properties of Welded Seams," *Jour. A. W. S.*, Jan. 1931, p. 24.

Abstract of article in Bulletin 336, *Verein Deutscher Ingenieure*. Static tests in Germany have demonstrated the superior ductility and strength of welds made with covered electrodes as compared with bare or dipped electrodes.

13. Texter and Speller, "The Quality of Materials for Fusion Welding," *Jour. A. W. S.*, June 1931, pp. 21–24.

The effect of base and filler metal composition on the quality of fusion welding is discussed. "Experience has shown that the success or failure in fusion welding steel of 0.20 to 0.30 per cent carbon and higher depends upon the use of a suitable flux applied either as a covering over the welding rod or deposited in the groove. . ."

14. "Welded Bridges and Buildings," *Jour. A. W. S.*, June 1931, pp. 27–34.

A summary of welded bridges and buildings in the United States and Cuba, containing a brief description of each job.

15. R. Schönhöfer, "The Most Economical Arrangement of Flange Plates in Welded Plate Girders," *Stahlbau*, **4,** 181–183 (1931).

The author points out the particular suitability of plate girders for welded construction. Where a variable section modulus with constant depth is required, one may use cover plates in layers as in conventional riveted practice. It is much better, however, to use a solid flange with butt joints where changes in thickness are required. Such a flange requires less welding and is more economical of material, particularly as the section properties may be made to approach more nearly to the desired values. Simple butt welds between portions of the flange are declared to be of insufficient strength, it being better to add cover straps on the inside face of the flange. The author also gives a method for determining the economical number and disposition of flange joints.

16. A. Massenberg, "Welded Railroad Bridge with Spans Up to 50 Feet," *Bauingenieur*, **12,** 705–710 (1931).

The article describes a coal unloading bridge (single track) 600 feet long built for a Berlin gas works. The bridge is a continuous plate girder. Proof tests on portions of the girder in a special large testing machine were used to substantiate the design calculations. Inelastic deformations were observed at low loads in the flanges, these being ascribed to readjustment of internal stresses.

1932

17. F. Faltus, "Largest All-Welded Bridge Built in Czechoslovakia," *Eng. News-Record*, **108,** 439–440 (1932).

Description of a Warren-truss highway bridge of 161-foot span at Plzen. Gusset plates were used only at the end joints. Bare electrodes and direct current were used.

18. D. Rosenthal, "Effect of Ductility on Security in Welded Connections. Method of Its Measurement," *Jour. A. W. S.*, May 1932, pp. 5–9.

Discussion of the function of ductility in enabling the welded connection to perform more efficiently. The author proposes to use the notch-impact test to measure the capacity of welds to successfully withstand concentrations of stress.

19. F. Eder, "Inspection and Tests of Welded Structures," *Jour. A. W. S.*, June 1932, pp. 11–15.

A discussion of the points concerning the welding process and the appearance of the weld which should be watched for in welding inspection. It is emphasized that effective visual inspection is possible only at the time of welding.

20. Hollister and Gelman, "Distribution of Stresses in Welded Double Butt-Strap Joints," *Jour. A. W. S.*, Oct. 1932, pp. 24–31.

This article reports the result of photoelastic studies and strain measurements on actual joints of the strapped butt type using fillet welds. The strain-gage readings are converted into stresses by multiplying by the modulus of elasticity, making no allowance for two-dimensional stress. Though this leads to large errors, nevertheless the data furnished by the investigation are valuable in forming a qualitative picture.

21. E. Pohl, "Statistical Study of the Quality of Welds and the Capability of Welders," *Stahl und Eisen*, **52,** 917–922 (1932).

The author reports the result of a statistical analysis of the quality of work of five welders. Arc-welded butt joints were used as specimens. The welders were graded on appearance of bead, inclusions and blow-holes revealed on machined and etched sections through the weld, scleroscope hardness value, tensile strength, elongation, angle of cold bend and bending elongation in the weld metal. Distribution curves are shown giving the scatter and frequency of the results obtained by each welder. The author points out the advantage of such studies in obtaining a figure for the reliability and uniformity of a welder's work.

22. Bernhard and Matting, "Testing Welds by Drilling and by X-rays," *Stahlbau*, **5,** 114–116 (1932).

The testing of welded seams by two methods is compared. Schmuckler's method is to drill a hole into the bead with a 90-degree countersink drill, thus removing weld metal only and giving a cross section of the seam. This is compared to radiographic methods. The authors conclude that X-ray examination is preferable to the Schmuckler method, giving a much more complete picture instead of the random sections revealed by the drill. Photographs of comparative weld defects are given.

23. H. Michel, "Review of Welded Bridges," *Revue Universelle des Mines*, Series 8, **7,** 372–373 (1932).

The author summarizes the achievements in welded bridges up to the first part of 1932 and lists thirty-five structures actually built from 1922 to April 1932.

24. E. Gaber, "Interaction of Rivets and Welds in Tension and Compression," *Bauingenieur*, **13,** 290–294 (1932).

The author describes static tests of the strength of strapped butt joints riveted and reinforced by longitudinal fillet welds. In order that the rivets should carry a fair share of the load, it is necessary that the welding be applied when the joint is under substantial stress. In the tests described, the preliminary load was chosen as one-half the allowable load. If the section of weld metal added is less than twice the rivet section and the individual welds are not too long, the author concludes that rivets and welds work well together. If too much reinforcement is added, the joint becomes so stiff that the welds carry practically all the additional load.

25. First Congress of the International Association for Bridge and Structural Engineering, Paris, May 1932. Final Report, 215–342.

This volume contains the reports of the round-table discussion on welding of structural steel presided over by Professor T. Godard.

The following points are worthy of note:

(*a*) Dr. Kommerell of the Central Technical Bureau of the German State Railways calls attention to the fact that the use of electrodes which are too heavy prevents adequate penetration at the root of fillet welds. He states that the German State Railways are adding the following requirements to their welding specifications:

Bare and lightly coated electrodes up to 0.16-inch wire thickness may be used for fillets up to 0.24 inch. Heavily coated electrodes of at most 0.12-inch wire diameter may be used on fillets up to 0.20 inch. A preliminary pass at the root is required for all heavier fillets. Exceptions to these rules will be granted for coated electrodes if the user is able to prove that his technique gives adequate root penetration without excessive penetration along the legs of the fillets.

(*b*) Prof. M. Ros, Director of the Federal Bureau for Testing Materials at Zurich, proposes formulas for allowable stresses in welded joints under repeated loading. Under tension, or under alternating tension and compression, the allowable working stress is given by

$$f_0\left(1 + 0.4\frac{A}{B}\right),$$

where f_0 is the so-called primitive fatigue strength in tension, that is, the strength of the material under two million applications of the tensile stress, the specimen being unloaded after each application. A is the numerically minimum value, B the numerically maximum value of the force, bending moment or stress (A and B shall be given appropriate signs to take care of stress reversal). For stresses varying inside the compression range only, the allowable stress is given by

$$f_0\left(1 + 0.3\frac{A}{B}\right),$$

f_0 here being the primitive fatigue stress in compression. The above refers only to tensile or compressive stresses. The allowable shearing stress is 0.7 of the above for butt welds and 1.2 of the above for fillet welds.

Under two-dimensional stress, an equivalent normal stress shall be calculated from the formula

$$f_{\text{equiv.}} = \sqrt{f_x^2 + f_y^2 - f_x f_y + 3s^2}$$

where f_x and f_y are the normal stresses and s is the shearing stress.

Values of f_0 for various types of welds and joints are tabulated and allowable stress range is plotted against minimum stress in the load cycle.

Welding is officially allowed in Switzerland for buildings, for plate-girder railroad bridges, and for both plate-girder and truss highway bridges.

(*c*) Dr. Albert Dörnen comments on the internal stresses produced by welding. His experiments indicate that the internal stresses in a welded girder are less than the corresponding stresses in rolled beams. Experience has shown that the latter may be neglected with safety and he argues that a corresponding neglect of internal stresses in welded joints is even more justifiable.

Of course, the internal stresses should be kept as small as possible, and to this end he suggests attention to the following points:

(1) Proper sequence of welding.
(2) Avoidance of superfluous and unnecessarily heavy welding beads.
(3) The use of light electrodes at low welding currents.
(4) Peening of welds with a light air hammer.

(*d*) J. Ridet of the French Eastern Railway describes heavy-duty spot welding which has been used in French building construction since 1930. A 46-foot span single-story building has been constructed using spot welding throughout in the place of rivets.

(*e*) Dr. S. Bryla describes the development of structural welding in Poland, the first country to issue official specifications (1928) for the use of welding in the fabrication of buildings and bridges. The first all-welded structures were built in 1927 and since then a number of structures have been built (up to 1932, the date of the discussion), including several small bridges, a seven-story postal savings bank (entirely welded), and the sixteen-story Prudential building in Warsaw, which was shop-welded and field riveted. There was a saving in weight in each case amounting to from 10 to 22 per cent over conventional construction.

He goes on to describe certain respects in which the Polish specifications differ from others. In particular he criticizes the use of a constant allowable shearing stress for all fillet welds regardless of size, pointing out that tests indicate definitely that smaller fillets can carry larger stresses. He proposes a formula for allowable shearing stress which takes the size of fillet into account.

(*f*) J. Caldwell, London, reports on the developments of welding in the British Empire. He remarks that British practice has always held strongly to the heavily coated electrode.

In reinforcing existing riveted structures by welding, it is claimed that "the strength of a combined riveted and welded joint may be estimated as the ultimate strength of the welding plus the yield-point strength of the riveting."

(*g*) Professors F. Campus and A. Spoliansky of the University of Liège discuss the Vierendeel bridge at Lanaye. This bridge is shop welded with riveted field connections. Details of the bridge are shown in drawings and photographs on pages 255–258. Static tests on a typical connection are described.

(*h*) Dr. H. Schmuckler, Berlin, discusses his method of testing welds by drilling (see ref. 22). A photograph shows the drill and the appearance of a defective weld as revealed by his process. He claims that it is especially valuable as a check on individual work in the shop. In the Schlachthof bridge at Dresden, the test holes were left unfilled and were covered with a transparent varnish for later inspection. There is, however, no reason why the test holes could not be rewelded.

(*i*) Dr. H. Kayser, Darmstadt, discusses the combined action of rivets and welds. He claims that his work and that of Dustin show that good results can be obtained by reinforcing riveted joints by welding. Correctly designed joints have a strength of the full value of the welds plus two-thirds of the strength of the rivets. By "correctly designed" Kayser explains that he means that welding is used only in side fillets and that the elastic behavior of the joint is taken into consideration so that the rivets can deform sufficiently to take their share of the load. Figure 1, page 318, illustrates what he means by correct design.

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26. F. P. McKibben, "Erecting Steel Buildings and Strengthening Steel Bridges by Welding," *Jour. A. W. S.*, May 1933, pp. 6–16; June 1933, pp. 4–14.

The article describes qualification of welders, flame cutting and welding design in general. Many structural details for new welded construction and for repair and reinforcement of riveted structures are given. Flame cutting is discussed critically and some comparative test data are given on flame-cut *vs.* machined specimens.

27. R. M. Gooderham, "Arc Welding Bridges in Great Britain," *Jour. A. W. S.*, July 1933, pp. 11–13.

Description of the design and construction of the first arc-welded bridge in Great Britain. It is a plate-girder highway bridge of 62-foot span.

28. O. Graf, "Experimental Results as a Design Basis for Welded Construction," *Stahl und Eisen*, **53**, 1215–1220 (1933).

This article describes in general the experimental results obtained by the author on the strength of welded joints under repeated loading, comparing butt and fillet weld connections. Curves are given showing the allowable stress range under repeated loading for various of the static stress component.

29. Schulz and Püngel, "Shrinkage Stresses in Electric Butt Welds," *Stahl und Eisen*, **53**, 1233–1236 (1933).

The article describes measurements of the deformations produced in welding butt joints in $^1/_4$- and $^3/_8$-inch plate of both ordinary and high-strength structural steel. The latter was a German St 52, containing 0.18 per cent carbon, 0.5 per cent silicon, 0.9 per cent manganese, 0.5

per cent copper and 0.5 per cent chromium, having a yield strength of 61 kips per sq. in. Both bare and covered electrodes were used, the composition of the electrodes being given in table 2 of the article. It was found that noticeably smaller internal stresses and deformation were produced in the specimens of high-strength material, this being ascribed to the superior high-temperature strength of the latter compared with steel of the ordinary structural grade. Covered electrodes produce higher internal stresses than bare electrodes. Double-layer welding with the two passes made in opposite directions led to reduced stresses. The internal stresses were slightly higher in the heavier plate.

30. Kommerell, "The Present Position of Welding in Steel Construction," *Stahlbau*, **6**, 41–45 (1933).

The author discusses the developments that have taken place in welding since the first German specifications were issued in 1931. In particular he calls attention to the new information on the importance of fatigue strength of welded joints. He suggests modifications in the specification to bring it up to date. The German State Railways are requiring that all the heavier fillets shall be given a preliminary pass at the root with small diameter wire in order to assure good penetration and to minimize thermal stresses and distortion of the work (see also ref. 25*a*). It is recommended that weld and base metal have approximately equal strength properties and ductility. The author criticizes the claim that penetration is not to be regarded as a weakening of the section, asserting that there are some cases, such as end fillets, where the claim is untrue. He also criticizes strongly the specification clause restricting the use of butt welds, calling attention to their superior static and, particularly, their superior dynamic strength. It is claimed that modern covered electrodes make it possible to produce butt welds which are entirely reliable. The author looks to butt welds as the way to a safe increase in working stresses and to a more economical construction using more fully the structural advantages peculiar to welding.

With regard to internal stresses in the welded structure, the author is of the opinion that their effect on the strength of the structure is negligible, provided that good ductility of both base and weld metal has been provided. As a test of the capacity of welded seams to undergo the small plastic readjustments necessary to carry such stresses safely, he endorses the suggestion due to Malisius that a tensile test be made of a plate specimen bearing a longitudinal welding, the combined specimen of weld and base metal being required to show a certain minimum elongation before cracking in the weld metal. It is said that some special-quality rods give as much as 15 to 20 per cent elongation in this test.

The author proposes a method of taking fatigue stresses into account in design. The member or joint is to be designed so that the allowable stress under static loading is not exceeded by the product of the nominal stress (maximum load divided by area of section) and a factor which depends on the ratio of minimum to maximum load. The factor is taken from a tabulation for the corresponding ratio and the grade of steel used and is greater than or equal to unity. Thus the member is to be designed so that

$$f_{all} \geq C \frac{P_{max}}{A},$$

where f_{all} = allowable stress under static load,
P_{max} = the numerically greatest load in the member,
P_{min} = the numerically least load in the member,
A = the appropriate sectional area of member or weld,
C = a factor depending on the value of P_{min}/P_{max} and the mechanical properties of the material. It is never less than one.

P_{max} and P_{min} are positive for tension and negative for compression, so that the ratio of these quantities is positive when there is no reversal of stress and negative when the stress is reversed.

The author gives the following formula for C:

$$C = f_y/f_p + (f_y/f_p - f_y/f_r)P_{min}/P_{max}$$

where f_y = yield strength of the material,
f_p = "Primitive fatigue strength," i.e., the fatigue strength of the steel when there is no reversal and the minimum load in each cycle is zero,
f_r = fatigue strength under symmetrically reversed stresses.

This formula is to be used only when the value of C so obtained is greater than unity; otherwise the value of C shall be taken as one.

For the German standard grade structural steel (St 37), this formula gives

$$C = 1 - 0.3P_{min}/P_{max}$$

and thus $C = 1$ when there is no reversal of stress and reaches a maximum value of 1.3 when the stresses are fully reversed.

For the high-strength steels conforming to the specification for St 52, the equation is

$$C = 1.2 - 0.3P_{min}/P_{max}$$

The deviation of these formulas is based on a simplification of the results of fatigue tests such as is given by the diagrams of Fig. 1 of ref. 31 (see accompanying separate abstract). Kommerell shows that the use of the formulas of the German specification DIN 4100, Part II, is excessively conservative in comparison with his formulas.

The author describes the method of the German State Railways of attaching flat plate stiffeners to welded plate girders. The stiffeners are beveled at the inner corners to give ample clearance to the web-flange fillet. Fillet welds attach the stiffener to the web and to the compression flange. The stiffener is not welded directly to the tension flange on account of the reduction in fatigue strength caused by transverse beads on this flange. A small square piece of plate is inserted between the stiffener and the tension flange and fillet-welded to both stiffener and flange, the flange welds running in the longitudinal direction and thus having little effect on the fatigue strength.

The author says that enough is now known that the use of welded plate girders is absolutely sound for all kinds of loading. The same cannot be said for welded truss construction, and this problem has yet to be settled. It appears, however, that welds of high strength and high ductility are necessary. There is, of course, no objection to the use of welded members with riveted connections.

This article is particularly authoritative, since the author holds an important position with respect to the welding work of the German State Railways and is one of the principal authors of the German welding specification.

31. Schulz and Buchholtz, "The Strength under Repeated Loading of Riveted and Welded Joints in St 52 (High-Strength Structural Steel)," International Assoc. for Bridge and Structural Engineering, Publications 1933–1934, II, 380–399.

This article and the following one, extensive abstracts of which have been published by the A. I. S. C., are representative of the extensive work which has been conducted in Germany (up to 1934) on the fatigue strength of riveted and welded joints. The work reported is part of an extensive research program in which the steel makers, the German State Railways, the technical schools and the state are cooperating. The purpose of this work is to determine the governing conditions for the use of high-strength structural steel, riveted and welded. In order to make a full comparison with structural steel of the ordinary grade, a number of collateral researches on the standard steel (St 37) have been undertaken.

It should not be assumed that these two articles stand alone, but they should be considered as representative of a much larger body of research. The work of O. Graf may also be cited as an important contribution to our knowledge of the fatigue strength of riveted and welded connections.

32. K. Schaechterle, "The Strength under Repeated Loading of Riveted and Welded Joints," International Assoc. for Bridge and Structural Engineering, Publications 1933–1934, II, 312–379.

See note to preceding reference.

33. C. S. Lillicrap, "The Use of Electric Arc Welding in Warship Construction," *Trans. Inst. Naval Architects* (Great Britain), **LXXV**, 45–58 (1933).

The author gives the views of the British Admiralty on welding in naval construction. He lists the following "essential considerations:"

"(1) *The Effect of the Welding Process in the Parent Metal.*—The heat disturbance caused may seriously affect the physical properties of the parent metal; and this is particularly the case with certain high-grade alloy steels.

"(2) *The Quality and Physical Properties of the Deposited Metal.*—Good parent metal combined with suitable good deposited metal gives the best chance of obtaining a satisfactory result in combination.

"(3) *Ductility.*—Ductility is of primary importance for our work. To get it we are prepared to sacrifice to some extent ultimate tensile values. There are electrodes on the market giving a very high ultimate tensile value but poor ductility. For such electrodes we have very little use in ships and the electrodes used are selected with this consideration in mind.*

"(4) *The Always Present Menace of Residual Stresses.*—It would be easy to be an alarmist over this matter, but there is no doubt that it can be countered and to a large extent avoided by careful design and correct procedure in the actual welding operation. This consideration has had a large influence in determining the type of joints and the procedure which we have adopted.

"(5) *Distortion and the Steps Necessary to Reduce It to a Minimum.*—As would be expected, this trouble is most in evidence when dealing with thin plating. Special care has to be taken in keeping the ship to form during building; and only actual experience can show the methods which will give the best results.

"(6) *Resistance to Shock—Gun Fire and Blast.*—In the past this consideration has given us a great deal of trouble; the intensity of the stresses suddenly set up appears to be outside the range of the ordinary laboratory shock tests, but with the procedure now adopted, and using certain electrodes, recent experiments and full-scale trials have shown that welded structures can be made to stand up to this form of shock with reasonable certainty.

"(7) *Corrosion.*—Some troubles from this cause have been experienced in the past. They have, however, not been serious.

"(8) *Fatigue.*—Some mention should perhaps be made of the possible failure of welded connections from what is usually described as 'fatigue.' There is a large field for investigation here. Some experiments on specimens built up of all-weld metal have, I know, been carried out to determine the fatigue limits, and a certain amount of work has been done on welded butt joints; but as far as I am aware nothing of importance has been published on lap joints with fillet welds.

"We would like more information on this important matter and in time I have no doubt it will be forthcoming.

"The whole question of 'fatigue' bristles with controversy, but I am inclined to believe that ductility again comes into the problem to this extent; that although good ductility does not necessarily mean high 'fatigue' value,** yet the high localized stresses consequent upon a lack of ductility are likely to lead to earlier 'fatigue' failures in a welded structure."

With regard to the effects of the type of base metal, the practice is to use great care with the high-tensile and galvanized steels. It is undesirable to have a carbon content greater than 0.35%. "Even so, we have had to approach the welding of this steel with great caution and the method of procedure which we have adopted and which is outlined later is the outcome of an extensive series of experiments. Only the highest grades of electrodes are suitable for this work." (The steel referred to is probably "Admiralty D steel," a carbon-manganese type.)

Cleanliness of the work when ready for welding is emphasized. Thin applications of light oil for preservative purposes, however, have not been found to have any effect on the strength of the joint, although the arc is liable to become somewhat irregular.

The careful fitting of parts prior to welding is emphasized. At least as much care, if not more, should be used in this regard than is customary with riveted work.

Work should be laid out so that as much welding can be done on the flat and as little as possible of overhead welding in place. In the yards, slabs or grids are used alongside the ship for assembling and welding.

To avoid distortion and residual stresses, small-gage electrodes are used with repeated runs over the seam as indicated in Tables 1 and 2, pages 52–53.

Flame cutting, particularly for the higher-strength steels, is viewed with some suspicion, and is not allowed.

Careful training and supervision of welders are emphasized.

"It is the general policy of the Admiralty now to use electric welding extensively in lieu of, or to supplement, riveting.

"Some care has to be exercised when welding and riveting are used in association; and in the future—I am optimistic enough to think not far distant—it may not be necessary to adopt anywhere this composite method of construction. For one thing, it is essential that the riveting should be done after any welding in the vicinity has been completed. There is also the difficult question as to the proportions of the load taken by the welds and by the rivets. The action is probably extremely complicated, but it seems clear that the welds must take the whole of the load until the stress in weld metal reaches the limit of proportionality; after which the rivets may or may not take their share of the load, according to the

* It is stated later that heavily coated electrodes are used exclusively.

** Evidently the author means high fatigue strength in a specimen of the homogeneous material.

degree of ductility possessed by the weld metal. The joint generally fails by successive fracture of the welds and rivets. Statements have been made that the ultimate strength is equal to the strength of the weld plus approximately two-thirds of the rivet strength; but our own experiments with ordinary shipyard practice certainly do not enable us to endorse such statements."

Practically all bulkheads are fully welded, with a saving in weight of ten to fifteen per cent and an initial cost little, if any, greater.

"In general we have adopted lap joints with fillet welds instead of the butt joint. In certain cases it may be necessary to use the butt joint; but we endeavor to reduce such joints as much as possible and use the lap joint wherever practicable. The difficulties of assembly are less and the residual stress problem does not reach the proportions which are inherent in the butt joint; at the same time the cost is less as there is generally no necessity for accurate machining."

End craters on fillets are mentioned as a source of trouble.

The practice has been adopted of making the shear leg about one-sixteenth inch longer than the tension leg of fillet welds.

Tables 1 and 2 and the accompanying figures give details of electrode gage, number of runs and their arrangement, types of V, etc. Single-V butt joints are given a final run on the back surface.

Appendix I describes an experimental determination of residual stress in a butt-welded joint in half-inch plate. The bars were welded at the free ends to a 9-inch slab and welded with six runs of the rod. Strain gages on the bars indicated the residual stress. After final cooling this was nearly 20 kips per sq. in. Similar results were given by $^1/_4$-inch plate with three runs.

Appendix II describes the repair of cast-steel A brackets.

Appendix IV gives the results of tensile tests of single-lap joints with end welds, one weld being smaller than the other.

Appendix V gives the results of tensile tests of several butt-welded joints.

34. E. G. Coker, "Stress Distribution in Fusion Joints of Plate Connected at Right Angles," *Trans. Inst. Naval Architects* (Great Britain), **LXXV,** 69–76 (1933), with diagrams on plates V, VI and VII at the end of the volume.

This article is a description of photoelastic tests of angle and tee joints between plates. Variation of forms of fillet and the presence of discontinuities inside the weld (lapped faying surfaces) were studied. The results are best seen by examination of the diagrams of plates V, VI and VII at the end of the volume. These diagrams indicate the two-dimensional stress distribution (under perfectly elastic conditions) in the joints studied.

35. B. P. Haigh, "Constructional Tests on Mild-Steel Rolled Sections with Electrically Welded Joints," *Trans. Inst. Naval Architects* (Great Britain), **LXXV,** 59–68 (1933), with diagrams on plate IV at the end of the volume.

36. Discussion of the papers by Lillicrap, Coker and Haigh, refs. 33, 34, 35, *Trans. Inst. Naval Architects* (Great Britain), **LXXV,** 77–96 (1933).

Discussion by J. L. Adam:

The discussor questions the Admiralty's stand on welding of gas-cut material, stating that these are private yards that do all the edge cutting of plates to be welded by the use of the torch.

He is further inclined to disagree with the remarks (in the paper by Lillicrap) on the relative merit of lap and butt welded joints. The tests of residual stresses in butt joints are objected to on the grounds that they do not represent structural conditions and are actually more severe. Residual stresses may be of quite equal importance when working with lap joints. The question of the care required to fit butt joints applies equally well to lap joints and the discussor considers that many fillets are run with poor penetration at the root because of badly fitting lapped plates.

The discussor comments that the specification for butt welding used by the Admiralty is quite satisfactory for some heavily coated rods, but in many cases different procedures may be followed with excellent results. Thus, in a single-V butt joint in $^3/_8$-inch plate, the edges were beveled at 60° by an oxy-coal gas torch. The gap at the root was left a little wider than usual, and the first run was made with a number 10 electrode, using a current density about 10 amperes above normal, so that about 5–6 inches of weld were obtained per electrode instead of 9 inches. "Penetration is obtained because of the higher current, but also brittleness and shortness in the weld. This latter defect was cured by the top run which was laid down with a number 8 electrode at the lowest current that gave fusion and at approximately 9 inches of deposit per electrode. The tensile and bend tests of these butt welds were as satisfactory as anything we have obtained with other welds."

Discussion by B. S. Varty:

The discussor represents the French classification society, the Bureau Véritas. He expressed the opinion of the Bureau that electric welding of ships is desirable and should be encouraged.

In answer to objections that several of the connections that he tested were impractical or else were designed in departure from accepted good practice, Prof. Haigh stated that many of his specimens were designed to illustrate certain features in the laboratory tests rather than to test actual connections, while on the other hand many of the specimens reproduced the essential features of connections that had actually been used in construction.

37. H. M. Priest, "The Practical Design of Welded Steel Structures," *Jour. A. W. S.*, August 1933, pp. 3–22.

This article discusses the types of welding and of welded joints, qualification tests for welders, inspection of welded work, stress distribution in fillet welds and in weld groups, and discusses extensively the design of welded structural details. The information is well documented and has the great advantages of being definite and detailed.

38. "The Electrically Welded Bridge in Dresden," *Bautechnik,* **11,** 157–169 (1933); also *Zeit. Verein Deutscher Ingenieure,* **77,** 431 (1933); and R. Leonhardt, *Eng. News-Record,* **111,** 589 (1933).

This bridge consists of two partially continuous plate girders 6 ft. 7 in. deep in thirteen spans of a total length of 1035 ft., containing 515 tons of steel. All connections were welded, except for the attachment of stringers to floor beams, which were riveted and bolted. The main girders were fabricated largely by automatic welding. No overhead welding was used. The total cost was 520,000 RM, or 140 RM per square meter.

39. Institution of Mechanical Engineers (British), May 31, 1933. (As reported in Zeit. V. D. I., June 10, 1933, p. 626.)

The Welding Research Association of the Institution of Mechanical Engineers met on the above date to discuss the influence of heat treatment of welded joints on the mechanical properties of the structure, and also the necessity of heat treatment to reduce internal stress. It appeared that a heat treatment which produces complete recrystallization of the weld metal (at 650° C. or 1200° F.) followed by slow cooling leaves a coarse grain and results in a slight embrittlement of the weld metal as revealed by notched-bar impact tests.

Izod impact tests were likewise made on weld metal from bare and covered electrodes.

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40. H. H. Moss, "Oxyacetylene Cutting of Structural Steel," *Jour. A. W. S.*, June 1934, pp. 8–12.

This article proposes a complete specification for the gas cutting of structural steel.

41. "Australian Rules for the Design and Construction of Metal Arc Welding in Steel Buildings," *Jour. A. W. S.*, July 1934, pp. 15–18.

42. G. A. Nikolaieff, "Investigation of Welded Bridges," *Jour. A. W. S.*, July 1934, pp. 19–23.

This article describes the experimental investigations and experience with construction of welded bridges in Russia.

When welding 80-inch diagonals (angles approximately $4 \times 4 \times {}^{3}/_{8}$ in.) to the chords of a small (40-foot span) truss, the residual stresses were measured and were found to be from zero to 3600 lb. per sq. in. These are presumably axial stresses in the diagonal.

The design of a Pratt-triss railroad bridge of 148-foot span has been completed and the bridge is being fabricated.

43. J. Mathar, "Determination of Initial Stresses by Measuring Deformations Around Drilled Holes," *Jour. A. W. S.*, July 1934, pp. 24–29.

The method of measurement consists of taking the elongation of a half-inch gage length when a hole is drilled through the material removing practically all the material between gage points. The drill and strain gage are integral and in a compact form so that measurements may be made in any location or attitude that is desired. The instrument is calibrated on a tension specimen under constant load.

In an 8-inch rolled H-beam, longitudinal flange stresses were found up to 21 kips per sq. in. compression, and longitudinal tension stresses in the web as high as 30 kips per sq. in.

The investigation of stresses along welded butt joints gave the following results:

(1) Arc welded seams showed somewhat higher internal stresses than gas welds.
(2) Stresses in the direction of the seam are high.
(3) Internal stresses are higher in continuous than in intermittent welds.
(4) No differences were observed in the internal stresses in welds produced by bare and covered electrodes.

The author points out that these internal stresses are not nearly as dangerous as they seem provided the metal is ductile, and concludes that "the most important requirement for weld metal is a very high ductility."

44. German Standard Specifications for Welded Buildings in Steel (DIN 4100, third edition, August 1934. The complete specification includes also DIN 4100, part II, second edition, July 1933).

45. British Standard Specification for Metal Arc Welding as Applied to Steel Structures, British Standards Institution, specification no. 538–1934, March 1934.

46. F. Bollenrath, "Constrained Deformation in Welded Seams," *Stahl und Eisen*, **54**, 630–634 (1934).

The author uses the Mathar method (43) to determine the distribution of internal stresses in two plates butt-welded into a square specimen. Exceedingly high principal stresses are found, well above the tensile yield strength. This is explained by the author on the basis of modern theories of the limit of elasticity (maximum shearing stress theory, Hencky-von Mises theory), his experimental results indicating that all the welds were stressed locally right up to the point of yielding. It is claimed by the author that this condition is not dangerous, since the additional service stresses will produce a stress distribution of such character that brittle fracture cannot result, but that the stresses will relieve themselves safely by small plastic shearing deformations. It is further claimed that the best condition for safe release of internal stresses by plastic yielding is obtained when weld and base metal have equal yield strengths.

47. Kommerell and Bierett, "Static and Fatigue Strength of Riveted Connections Strengthened by Welding Applied While the Joint Is Carrying Load," *Stahlbau*, **7**, 81–85, 91–95 (1934).

The authors report the results of fatigue tests in pulsating tension of strapped butt joints. The joints were riveted and prestressed by repeated applications of tension, then reinforced by fillet welds applied to the joint while the latter was carrying a tension of the same order as the dead-load tension. Bare wire electrodes and direct current were used. The conclusions are drawn from the experimental data that the improvement in static strength given by the reinforcing welds affords no clue to the improvement in fatigue strength. In fact, it is possible to obtain large increases in static strength with no improvement in resistance to repeated loading. To obtain the best results from reinforced joints which are designed principally by repeated loading, the weld must be so disposed that they will permit the elastic deformation which accompanies the sharing of the load among the rivets in a row. The improvement in fatigue strength produced by reinforcement varies decidedly with the design of the original joint and with the disposition of the welds.

The original article is very detailed and presents much data that cannot be compressed into an abstract.

48. A. R. Moon, "Welded Steel Structures—Recent Developments in Europe," *Structural Engineer*, **XII**, 464–473 (1934).

The author describes the extent of welded construction in Europe as comprising "upward of one hundred railway bridges, thirty highway bridges, twelve multi-story buildings of six to twenty stories and some hundreds of factory buildings. . . ."

He cites economy, suitability and appearance as the three factors in the choice of the new method of construction.

The greatest advance in structural welding is said to have occurred in Belgium and Germany. Many industrial buildings have been built with rigid frame bents to take the place of wall columns and roof trusses. The superior appearance, better light and the freedom from interior columns is said to overbalance the extra weight of this construction as compared with the conventional steel construction using interior columns.

The use of welding in railroad bridge construction in Germany has developed from small plate girder bridges to the largest plate girders to be constructed. Considerable investigation of static and dynamic strength has been undertaken and some of the design details indicated by this work are described and illustrated. (For this information see articles by Schulz and Buchholz and Schaechterle, already published by the A. I. S. C.—ED.) The article is particularly well illustrated.

49. "The Pilsen Bridge," *L'Ossature Métallique*, Sept. 1934, pp. 442–443. See also *Elektro-schweissung*, July 1934, pp. 134–135.

The highway arch bridge at Pilsen in Czechoslovakia was opened to traffic last fall. It was the first arch bridge and the second highway bridge to be fully welded. The span is 165 ft. with a roadway of 20 ft. plus two 5-ft. sidewalks. The arch ribs are of plate girder construction 3 ft. deep. Two ribs are used. The ribs are hinged at the abutments, a detail of the construction at the hinge being given in a photograph. The ribs are connected horizontally by plate girders and further bracing is obtained by cross-bracing using light angles. The stringers, floor beams and spandrel posts are likewise of plate girder construction, all the members being assembled from flats.

The ribs weigh 53 tons, the total weight of the steel construction being 122 tons. The weight of the riveted structure is estimated to be 148 tons, or 22% more.

Excellent detail photographs are shown.

50. A. Spoliansky, "Bridge C at Hérenthals over the Albert Canal (Belgium)," *L'Ossature Métallique*, Sept. 1934, pp. 407–413.

This three-span bridge in Belgium is rather adequately described in the photographs. Attention should be drawn, however, to the side-span hinges ten feet from the piers, illustrated in Fig. 447, p. 412. A point of particular interest is indicated in the floor-beam connection shown in Fig. 444, p. 410: the shop construction is to build the girders with beveled stubs to which the beveled ends of the floor beams are welded in the field. No overhead welding was used. The weight of the bridge was 22% less than the previous riveted design. The bridge was fully welded.

51. Braeckman and van Gaver, "The Schooten Bridges over the Albert Canal in Belgium," *L'Ossature Métallique*, Sept. 1934, pp. 414–419.

This article describes two bridges across the Albert Canal which were shop welded and field riveted. The experience with welding proved so excellent that the bridge at Hérenthals (described in the same issue) of similar Vierendeel construction was built with the use of field welding and no rivets. The illustrations indicate the details sufficiently well.

52. "Arc-Welded Building at Messrs. Brown, Bayley's Works," *Engineering*, **138,** 407–408 (1934).

Describes the replacement of an old brick building housing a Bessemer plant by a modern steel building all-welded. Coated electrodes were used. An interesting and simple expansion joint at the end bearing of the same girder is illustrated (substantially a flexure-plate connection).

An interesting incidental remark notes that the same rail, formerly bolted, had worn into the old girder to about 1/4 inch, this being ascribed to wear due to scale and grit. The new rail is welded continuously to the girder. The old crane capacity was only 5 tons.

53. "Welded Arch Pipe for Water Supply," *Engineering*, **138,** 100 (1934).

In the Lausanne (Switzerland) water supply it was necessary to cross a portion of land in which considerable earth movements (extending to quite a depth) are known to occur frequently. The 20-inch pipe line was carried across this region as a self-supported arch of 138 ft. span and 23 ft. rise. Half-inch and 4/8-inch pipe was used with massive concrete abutments. The rise of the arch is 23 ft. The water pressure is 30 lb. per sq. in. Stiffening plates perpendicular to the pipe surface are used at the abutments. The pipe is entirely arc-welded, being fabricated in three sections in the shop, then field-welded in place. The abutments were poured after erection.

54. H. Gottfeldt, "Some Remarks on the Design of Panel-Point Connections in Welded Bridges," *Bauingenieur*, **15,** 200–203 (1934).

Basic rules for the design of trusses are explained and summarized in the principle that sudden distortions of the stress system are to be avoided. Riveted connections satisfy this requirement only incompletely. The same is true of most welded joints, the damaging effect being greater in welded structures. Only through the use of the butt weld may the stresses be maintained uniform, and on this account the butt weld is to be preferred. Connections are developed which use butt welds exclusively and thus satisfy the fundamental principle explained above.

55. Young and Jackson, "Rigidity of Welded and Riveted Joints," Technical Bulletin, University of Toronto, 1934.

Little quantitative information being hitherto available concerning the degree of restraint developed at the ends of steel beams and girders with welded connections, and the extent of possible related economies and improvements in frame stiffness being correspondingly uncertain, the experimental investigation of two distinct aspects of joint rigidity was undertaken. These were:

(*a*) The relative capacity under gravity load of beam-girder and beam-column connections for developing beam restraint, or continuity, designed with a view to reducing the required weight of the connected beam.

(*b*) The relative values of certain typical connections in resisting the deformation of a frame due to lateral loads, either in one direction or subject to reversal.

Two series of specimens were fabricated and tested in relation to plain rating beams. The first series, designed for the purpose of studying beam continuity, consisted of ten 9-in., 20.5-lb. Bethlehem beam double-cantilever specimens, employing five different types of welded connections. The second, designed primarily for the study of wind bracing rigidity, consisted of twelve 18-in., 47-lb. Carnegie beam double-cantilever specimens with three different types of connections. These types included the welded T, the welded gusset and, for comparison, the riveted T. For half the specimens of the second series the connections were to a central transverse plate simulating the web of a column, and for the other half to the flanges of a 12 by 12-in., 110-lb. H-column.

Coefficients of restraint, that is, the ratio of actual to 100% restraint, were ascertained by determining end slope angles with the aid of a special type of longitudinal extensometer attached to the beam flanges. Although, for convenience, the specimens were tested as double-cantilevers the results were readily transformed to be applicable to the partially restrained beams simulated by the specimens.

Story drift angles, that is, the angle through which the columns of a building subjected to horizontal force would

tilt in one story of height due to the deformation of the connections, were ascertained by utilizing the end slope angles mentioned above and the observed deflections of the specimens. The results for the specimens were transformed by calculation to be applicable to a 20-ft. bay of an actual building.

Broadly stated, the results obtained in the study of the connections tested were:

(1) Welded connections as ordinarily designed for end restraint fall short of the ideal value of 0.75 for the coefficient of restraint by from 10 to 25%.

(2) Both welded and riveted connections designed primarily for capacity wind moment develop a coefficient of restraint in excess of the most economical value (0.75) required to resist gravity loads only.

(3) A beam welded to a column web may develop less story drift angle than would a plain beam integral with the column. T's riveted to a column flange may, for a 20-ft. bay, give rise to a lineal drift of as much as 0.36 in. per 12-ft. story under a capacity wind in one direction, while welded T's under the same conditions showed 0.09 in. and welded gussets only 0.03 in.

(4) In the connections designed for beam continuity only, the compression attachment was in all cases more yielding than the tension one. Transfer of axial compression by longitudinal welds to the edges of a thin flange introduces much yield due to horizontal shear in the flange.

(5) In wind connections either to a column web or to a column flange, the top and bottom attachments, under capacity reversing load, gave approximately equal total longitudinal deformations for each of the three types.

(6) From a third to a half of the flexural slope in a connection to an unstayed column flange may be charged to the deformation of the column flange.

(7) In wind connections to an unstayed column flange the welded connections gave regional flexural slopes from 17 to 63% of the corresponding ones developed in the riveted T-connections, depending on the region, or longitudinal zone. Consequently, the welded connections were definitely stiffer than the riveted ones in all regions.

(8) The aggregate longitudinal elastic deformation in tension for capacity reversing load was greater than the aggregate deformation in compression, the maximum excess being 70%. This was for the riveted T-connection to a column web.

(9) For the riveted T's a large part of the longitudinal deformation was nonelastic slip. It amounted to 31% for the connection to a column web and 46% for a connection to a column flange.

(10) Welding of stiffeners to the column flanges reduced the longitudinal deformation of the welded T and the welded gusset connections to 75 and 85% of their previous values, respectively.

(11) For the specimens designed for beam continuity only, the ratios of the test factor of safety to the design factor of safety, based on an estimated ultimate strength of 10,000 lb. per lineal inch of $^3/_8$-in. fillet weld with uniform distribution of stress, varied from 0.65 to 0.97.

(12) For the specimens designed primarily as wind connections, the ratio of test factor of safety to design factor of safety, based on assumed uniform stress distribution, varied from 0.88 to 0.98 for the riveted specimens, from 0.49 to 0.83 for the welded T-specimens and from 1.06 to 1.29 for the welded gusset plate specimens. It is thus evident that non-uniformity of stress, which obviously existed to a marked degree for the welded T-connections, may cause the capacity of certain types of connections to fall considerably below that estimated on the basis of uniform distribution.

56. "Report on the Treatment of Welded Structures by the Metallic Arc Process," *Institution of Structural Engineers* (Great Britain), Dec. 1934, 166 pp.

The report is divided into four parts: critical description of the arc welding process, metallurgical study of welding, tests on welded members and recommendations for the control of welding in construction.

The first part gives an excellent detailed account of the welding process, explaining the mechanism of deposition, the differences in behavior of bare and covered electrodes and the characteristics of welds as affected by the position of the work. The effects of current and size of electrode are described. Specific recommendations with actual examples are given for the avoidance of distortion. Many excellent photographs and drawings add much to the value of the text.

It is recommended that the size of electrode and the length of run per electrode shall be standardized for each fillet size. Two-run deposits are considered unsatisfactory because of the necessity of weaving the electrode and it is difficult to ensure penetration over the whole area covered. If an electrode which is too heavy is used for a butt weld, the weld metal will heat up excessively, resulting in deep penetration along the sides of the bevel and an accumulation of slag at the root of the weld which prevents good root penetration.

The second part discusses the effect of composition of electrode, preparation of the work and conditions of welding on the metallographical characteristics of the weld. Excellent macrographs and micrographs illustrate this work, together with X-ray radiographs. The illustrations are the more valuable as they show examples of all kinds of welding, good, bad and indifferent.

Accelerated corrosion tests are described. Atmospheric corrosion tests are under way and will be the subject of a later report. Static strength tests on a welded truss, two welded plates and a welded column are reported. Comparison tests were made on similar riveted trusses and girders.

In part IV detailed recommendations are given for a specification for welding. It should be noticed that the recommended stresses are in general lower than those of the British standard specification of March 1934 (45). "As a check on the uniformity of the welding and on the skill of the workman, it is strongly recommended that a recording ammeter be provided on each machine to give a continuous record of the current used on each weld."

This report is outstanding for its copious and excellent illustration and for the detail of its description of the actual welding process.

57. "Welding by the Electric Arc," *Otua* (Office Technique pour l'Utilisation de l'Acier, Paris), Paris, August 1934.

This book presents an interesting variety of material pertaining to the use of arc welding in the construction of buildings and bridges. It is well and simply written to appeal to both technical and non-technical readers.

The first part, to page 96, is entitled "Generalities and Principles." It describes the various factors that determine the quality of a welded joint, the type of equipment used and the various basic design methods that have been proposed, together with incidental material of a general nature.

The first part contains much elementary material which needs no comment, but the following points may be of interest.

1. On page 33 it is emphasized that the lack of matching rivet holes makes it extremely important that each piece in the field be conveniently and explicitly marked

for ready location. Thus "top" and "bottom," "north end" or "south end" may well be marked on the piece. This is a point the importance of which may easily be overlooked by fabricators inexperienced in the erection of welded work.

2. It is recommended on page 43 that gusset plates be dispensed with as much as possible. Direct joints are to be preferred to strapped joints.

3. On pages 44–45 are found the following remarks on dimensions of welds.

(*a*) The throat (exclusive of reinforcement) should not exceed 70% of the thickness of the thinnest plate.

(*b*) The length of discontinuous welds should be restricted by upper and lower limits. In view of the undetermined behavior of the end portions of fillet welds, no load carrying fillet weld should be shorter than some minimum value in the range 4 to 7 cm. (1.6 to 2.8 in.). "An important number of authors" agree that side fillet welds should not be longer than 40 times the throat dimension, since greater lengths lead to excessive variation in stress along the length of the weld.

Some authors, on the grounds of economy in weld metal, recommend increasing the length rather than the root dimension in order to provide the adequate weld section. Other authors take a contrary attitude, claiming that a heavier bead works more effectively, the stresses tending to a more uniform distribution in the cross section of the bead.

4. On page 45 it is emphasized that special precautions should be taken to ensure uniform heating of the parts being welded, so that excessive deformation is avoided and the thermal stresses kept to a minimum. From this point of view, heavy sections are desirable. The order and direction of laying down rows of weld metal should receive judicious attention in order that symmetrical and uniform thermal effects are produced. Intersecting weld beads are to be avoided.

5. On pages 46–49 the following methods of avoiding deformations of the structure due to the welding are described:

(*a*) Set up the work with an initial displacement in the opposite to counteract that produced in the welding operation. The initial setting must be determined by experience and is a separate problem for each job.

(*b*) Assemble the work rigidly for welding, using, for example, tack welds and wedges between parts that tend to draw together (as in a long butt weld). The criticism of this course is that it gives rise to important internal stresses in the assembly.

(*c*) Locate the welds where they will produce the least deformation. For example, if it is desired to connect a tube to a flat plate which must remain truly flat, the plate can be punched and flanged to furnish a butt joint for the tube (see Fig. 21, page 47). The deformation in a welded square tube can be minimized as in Fig. 22, page 48, by running down one side instead of at the corner.

(*d*) Use forms in the assembly which will yield readily to the deformation in a predetermined way. An example is the fabrication of cooling jackets for aviation engines from sheet metal in which a crimp is put in the sheet parallel and close to the edge to be welded (see Fig. 23, page 48).

(*e*) Deposit the weld metal in discontinuous runs, either by welding backward to the end of the previous run, or by alternating from one side to the other of the work (see Figs. 24 and 25).

(*f*) Use narrow beads and repeated runs to obtain the full desired section of weld metal.

(*g*) Straighten the work cold by hammering or with a press. This must be done with caution to avoid damaging the welds.

(*h*) Straighten the work hot. "This is not to be recommended unless the welding rod is specifically designed not to be hot short."

6. On page 49 it is stated that thermal stresses are the subject of much controversy. They may be reduced by various methods, such as

(*a*) Peening of the cold weld. The amount of cold work has little deleterious effect on the physical properties of the weld metal.

(*b*) Annealing, which gives good results in some cases. Badly carried out, it may be useless or even harmful.

7. On page 50 it is said that some authorities advise the complete avoidance of overhead welding, or, at least, that such welds be considered to possess only 30–40% of the strength of normal welds. "Actual experience, however, has shown that such mistrust of overhead weld is not justified, and that by the use of suitable electrodes and experienced welders these welds are as strong as horizontal welds."

8. In Chapter 8, pages 54–58, four approaches to the problem of designing welds are described.

(*a*) The roughest method is to take into consideration merely the strength of the members to be connected and to weld in such a manner that the failure will surely occur outside the weld. Such methods lead in some cases "to a veritable debauch of welding."

(*b*) Other methods, such as those of the Bureau Véritas, compare the welded joint to an analogous riveted joint, the comparison being justified by experience. Where empirical methods of design of the riveted structure have prevailed (in marine construction, for instance), the accumulated experience of the designer expressed in the rules for riveted construction may best be used by such a comparison, the true stresses being unknown in both the riveted and welded cases. Such methods are inadequate where the welded structure departs noticeably from riveted practice.

(*c*) The welded assembly may be considered as broken down into a number of simple joints, the strength of each being determined by experiment. The strength of the assembly is taken as the sum of the component strengths. Experiments by H. Dustin (Proc. International Congress of Metal Construction, Liège, Sept. 1930) indicate that the strength of butt and end fillet welds are proportional to their size. Side fillet welds increase in strength less rapidly than the size increases. On the other hand, the Swiss experiments of 1922–23 indicate that end fillet welds also do not increase proportionally with the size of fillet.

Experiments have shown, however, that the strength of the entire joint may often be less than the sum of the strengths of the component welds and may be as much as 20% less, depending on the details of the assembly. To support this statement, reference is made to the Report of the Structural Steel Welding Committee, 1931.

(*d*) Other methods seek to take into account the various component stresses, tension, shear, bending, etc., on the various parts of the assembly. The full application of these methods demand, however,

the knowledge of the actual local distribution of stresses, about which little definite is known.

9. Chapter 9, pages 59–67, describes the design method of Haas (Berechnung der Festigkeit Zichtbogengeschweisster Verbindungen, Elektroschweissung, Jan. 1931). This method is said to have given excellent predictions of strength realized in tests. The basis is merely that the strength of the joint is given by equating the tensile strength of the weld metal (determined experimentally) to the maximum stress determined by the conventional engineering formulas assuming simple stress distributions. Certain cases, however, are solved by the use of approximate equations which are given in the text. For reference to the text, the following explanation of notation may be desirable:

a = throat dimension of weld
l = length of weld (reduced at the ends to allow for craters)
R = ultimate load of joint
K = tensile strength of weld metal
e = plate thickness

10. Chapter 10 describes the Belgian method of design of welded joints. It is based on a tensile strength of weld metal which is at least equal to that of the base metal. Butt welds are assumed to be capable of carrying the same stress as allowed in the base metal, end fillet welds 65% of the stress in the base metal, and side fillet welds from 40 to 50% (depending on size and length) of the base metal. Fillet welds making an angle of less than $31\frac{1}{2}°$ with axis of load are considered side fillet welds, other oblique welds are considered end welds. Joints combining various forms of welds are computed on the basis of the sums of the capacities of the individual welds, it being recommended, however, that a reinforcement of 10 to 20% be used, or an equivalent increase in length. In bending, the welds must be capable of taking the maximum tensile stress. The stressing of the welds is not broken up into normal stress and shear. It is said that these rules lead to a conservative design.

11. Chapter 11 describes the design methods of the German State Railways. (For the description of these methods, see the notes on the German Standard Specifications.)

12. Chapter 12 describes a design method due to Goelzer (Génie Civil, Feb. 2, 1929; Bull. Soc. des Ingénieurs Soudeurs, Jan.-Feb. 1931; same journal, Aug.-Sept.-Oct. 1932). The weld stresses are computed by dividing the total load by the longitudinal section of weld through the throat. In combinations of side and end fillets, the dimensions of side welds are chosen so that the stress in the end fillets is 52.6% of the stress in the side fillets. Goelzer claims that the stresses increase more rapidly in end fillets than in side welds as the load is applied, the end welds thus taking an increasing share of the load; this is the reason for the above-mentioned stress ratio for fillet welds. The rest of the procedure depends upon the use of a number of numerical coefficients which depend on the number, disposition and type of welds. (The explanation is not entirely clear in all details.) No mention is made of the confirmation of these formulas by tests. Examples are given, as for the other design methods.

13. Chapter 13 describes the American method.

This concludes the first part of the work.

The second portion of the book is devoted to examples of welded construction "chosen from recent publications." The authors take no responsibility for the merits of the examples, saying that they have not had the opportunity to verify the constructions by test.

For the most part, the text is mere description of the illustrations. Comments of possible interest from the text are given below:

1. Figure 111, page 111, shows a method of varying the moment of inertia of a rolled girder by cutting away a portion and bending the flange into contact with the remaining web, then fillet welding flange to web.

   A similar procedure in reverse is shown in Fig. 112, page 112, where the flange is bent down away from the web and a triangular piece welded in to fill the gap, the purpose being to develop a rigid beam-to-column connection.
2. Attachment of beams to column flanges by fillet welding on the beam web only (Fig. 217–218, page 154) is condemned as unsound except for very lightly loaded beams.
3. Kommerell (Congrés des Ponts et des Charpentes, Paris, 1932) is quoted as authority for an estimate of $\frac{3}{4}$ the maximum bending moment as a fair value for the end-fixation moment of a rigidly connected beam.
4. Note the stiffening of the column to resist the beam moment, Fig. 259, page 169, by means of plate connecting the flanges parallel to the web. The local increase in section properties probably has some advantageous points when the moment is large.

The third part describes flame cutting. A considerable part of this section is devoted to apparatus and the manner of use. The remarks on flame cutting apply largely to hand cutting. There seems to be little of particular interest in this section.

A bibliography of 109 references concludes the work.

58. Bulletin Number 3, June 1, 1935, International Assoc. for Bridge and Structural Engineering.

This bulletin contains photographs, sketches and brief descriptions of the following welded structures:

(*a*) Bridge at Tessin, Switzerland, 1933, Arc-welded plate stiffening girder of 214-foot span.

(*b*) Two similar highway bridges at Schooten over the Albert Canal in Belgium, 1934. Vierendeel trusses of 207-foot span shop-welded and field riveted. See also ref. 51.

(*c*) Highway bridge at Nuth, Holland. A Vierendeel truss entirely welded.

(*d*) Highway bridge at Stockholm (West bridge), 1935. Uses high-strength steel.

(*e*) Highway bridge over the Pålsund at Stockholm Deck arch of 185-foot span and viaduct of high-strength steel, all welded.

(*f*) Rába highway bridge in Hungary, 1934. A through Pratt truss of 175-foot span. Saving of weight in comparison with riveting 15 per cent.

(*g*) Fair hall at Basel, Switzerland, 1934. Three-hinged plate-girder frames shop welded.

59. K. Klöppel, "Where Does Welding Stand Today and What Rôle Do the Specifications Play?" *Elektroschweissung*, Hefte 4 and 5, 1935, 16 pp.

The adoption of welding was forced by economic considerations without our technical understanding of this new structural tool. In order for our technique to keep pace with its practical application, we have been compelled to undertake extensive investigations, both in the laboratory and by construction of experimental structures. The advances have been great. In the five years since the adoption of the German standard specifi-

cation, three revisions of this specification have been required. This year the German State Railways will have some hundred welded bridges in operation. It is therefore appropriate to review the rapid technical progress of recent years and to assess the present position.

No defects have developed so far in the purely structural regulations of the specification, but some difficulties with the specification arise when attempts are made to use new features of welded construction indicated by reasons of economy. An example of this is afforded by the thousand-foot Schlachthof bridge (38) at Dresden. Low cost was an important item in this bridge since a cheap alternative design in wood had been prepared. Experience had shown that shop labor costs per ton were higher on welded than on riveted work. Reduction in this item was obtained by the use of machine welding on the web-flange fillets, amounting to a considerable proportion of the total welding in the bridge. Since the possible economy of a welded as compared to a riveted bridge depends more on the length of welding per ton than upon the total weight saving, it was decided to dispense with their consequent longitudinal fillets and to use instead butt-welded single flange plates, the thickness being varied along the span. According to the specification, the conventional butt joint was of insufficient strength for the purpose. This difficulty was circumvented by the use of a butt joint shaped in plan like a V.

The recognition that the reduction in labor costs is of greater importance than the over-all weight saving has led to the use of single flange plates of very great length (Hamburg bridge, Fig. 4 of the article) and, of course, of a thickness corresponding to the maximum section required. Recently the reduction in welding has gone so far that structures formerly requiring 130 feet of welds per metric ton are now being designed with 100 feet of welds per ton. Further savings along this line are being made by the use of suitable special rolled sections in the place of built-up members.

On the other hand, some of these advantages are offset by the higher unit costs of long and heavy plates, increased weight tolerances and handling difficulties. The number of simultaneous operations that can be performed in the fabricating shop is less for welded than for riveted construction and this means that welded work moves more slowly through the shop. Drafting room costs are, however, lower on welded construction. An important element in economy of welded work is the extensive use of gas cutting.

The Dresden bridge and the Berlin coal unloading bridge (16) furnished important indications of the considerable thermal contraction on long bridges. On the former, further contraction was produced when the stiffeners were attached subsequent to the welding of the flanges.

The author gives an excellent survey of the information gathered from the extensive German program of fatigue testing of welded joints. He points out that the tendency is to use butt welds more frequently than before on account of their superior qualities under repeated loading. High-class workmanship is demanded, special precautions being taken to eliminate undercutting at the edges of the bead and to ensure perfect penetration at the root. Web joints in standard grade structural steel are now being made by the State Railways in the form of simple butt joints using an angle of vee greater than 90 degrees. The allowable stresses on such a joint are the same as for the base metal. The use of these joints at base metal stresses has not yet been allowed for the higher-strength steels. The analogous extension of this to flange joints presents more of a problem, since the production of high-grade butt welds in heavy plate is particularly difficult.

Photographs show the transportation of complete bridges and large girders to the erection site. For the Rügendamm bridge the two 175-foot plate girders were entirely fabricated in the shop (perhaps a field shop, the article not being entirely explicit on this point). The flanges of this bridge were 20 x $1^{5}/_{8}$ in. in section and were delivered by the mill in full-span lengths.

Floor beam connections are required to carry 75 per cent of the fixed-end moment in addition to the shear. Though some conservation in design is warranted, as the strength of such connections under repeated loading has not yet been satisfactorily determined, this is considered too severe a design condition, since the torsional stiffness of the main girders is never great enough to develop so large an end moment. Further investigation of this point is needed.

The poor showing of fillet welds in fatigue have led to a distrust of welded trusses for dynamic loading conditions. Furthermore, the conditions of erection are such that more field welding is required than for plate girders. Both from the standpoint of economy and of strength the truss is therefore at a disadvantage. The Vierendeel truss form is much better suited to welding than is the triangular braced truss.

There is a tendency to call for more severe requirements on the qualification tests of welders and some firms are demanding from their welders results in excess of the specification requirements. The feeling is widely shared that the cold bend test is an unsatisfactory indication of the worth of the weld in a structure, that the results scatter widely and that it is more of a test of the electrode than of the joint or welder.

60. Symposium on the Welding of Iron and Steel. London, May 1935. Organized by the Iron and Steel Institute in cooperation with a number of other British technical societies.

The following papers are of particular interest:

(*a*) D. Anderson (London), "Welding in Bridges," 6 pp.

This paper describes a five-span rigid frame bridge carrying a highway across the London and North Eastern Railway at Newport, Middlesbrough, England. The bridge is designed to take an exceedingly heavy loading, a hundred-ton truck on four wheels (sic) plus 50 per cent for impact.

(*b*) Atkinson and O'Malley (Australia), "Bridge Welding Practice of the Railway Construction Branch," Victoria, Australia, 8 pp.

(*c*) W. T. B. McCormack (Australia), "Welded Steel Bridges in Victoria, Australia," 10 pp.

(*d*) H. Maier-Leibnitz (Stuttgart), "Application of Welding in the Construction of Rigid Frames with Solid Webs for Steel Structures (Particularly Roofed Structures)," 10 pp.

A description of types of welded rigid-frame construction in Germany.

(*e*) G. Roberts (Dorman, Long), "Design and Tests of Butt-Welded Joints," 12 pp.

Report of tests of static strength of butt welds in two-inch plate. A variety of forms of weld were used. The author recommends edge covers at the ends of the weld to eliminate local weakness. The better types of joint developed practically the full strength of the plate.

(*f*) W. D. Chapman (Australia), "Procedure Control of Electric Arc Welding in Australia," 6 pp.

Specification of welds by size of fillet, size of electrode, number of runs and length of each run.

(*g*) H. J. Gough (National Physical Laboratory), "The Welding Research Program of the Steel Structures Research Committee of the Department of Scientific and Industrial Research," 6 pp.

Describes the scope of the research program which includes a statistical study of the strength of welded joints and an investigation of non-destructive methods of weld testing.

(*h*) Ellson and Miller (England), "British Railway Welding Practice as Applied to Permanent Way and Bridge and Structural Repair Work," 24 pp.

Contains several detailed examples with drawings and photographs showing repairs to bridge structures.

(*i*) D. Arvidsson (Stockholm), "A Modern All-Welded Bridge in Stockholm," 12 pp.

Detailed account of the design and construction of the Pålsund bridge (see 58-*e*).

(*j*) H. Dustin (Brussels), "The Use of Welding in Large Civil Engineering Constructions in Belgium," 12 pp.

Describes the extensive construction program of welded Vierendeel bridges over the Albert Canal and the static and dynamic tests carried out in connection with this work.

(*k*) G. Ellson (Southern Railway), "Some Experiments to Ascertain the Effects of Strengthening Girders by Welding," 12 pp.

Static tests.

(*l*) Ros and Eichinger (Zurich), "The Strength of Welded Connections," 25 pp.

A report on static and dynamic strength of welded joints. The authors have done much original research on this subject and their conclusions may be considered authoritative. Many diagrams (with experimental points plotted) show the strength of various connections for repeated loading with different values of stress range and mean stress.

(*m*) Mitchell and Martin (Dorman, Long), "Workshop Practice in Structural Steel Welding," 16 pp.

Description of fabrication methods, including jigging and avoidance of distortion.

(*n*) Benson and Allison (Metropolitan-Vickers), "The Low-Temperature Annealing of Welded Mild-Steel Structures to Relieve Internal Stresses," 10 pp.

Description of experiments to determine best conditions for stress-relieving by annealing.

(*o*) Boyd and Cape, "Distortion Control Procedure," 12 pp.

Discusses the above subject in general and the application of the methods to the fabrication of a complicated grid in heavy plate.

(*p*) O. Graf (Stuttgart), "On the Fatigue Strength of Constructional Members, and Particularly of Welded Joints," 4 pp.

A brief article from an authoritative source, but touching only the high points. The photographs of fatigue failures are good.

(*q*) B. P. Haigh (Royal Naval College), "Fatigue Strength of Butt Welds," 8 pp.

Report of some fatigue tests by an authority on fatigue testing.

(*r*) G. A. Hankins (National Physical Laboratory), "Fatigue Tests and Non-Destructive Tests on Welds," 6 pp.

Preliminary report on fatigue tests of welds for the Steel Structures Research Committee.

(*s*) S. Bryla (Warsaw), "Results of Tests with Rolled Beams Reinforced by the Aid of Welding," 14 pp.

The effect of welded plate stiffeners on the static strength of rolled beams.

(*t*) A. M. Roberts (Metropolitan-Vickers), "Fatigue of Welds," 12 pp.

Gives a brief but rather clear summary of the results obtained by Swiss and German investigators on the fatigue of welded joints. Reports the result of fatigue tests on some vibrating cantilever specimens.

(*u*) O. Bondy (London), "Relations between the Design and Fatigue Strength of Welded Structural Joints," 10 pp.

A review.

(*v*) W. D. Halsey (Hartford Steam Boiler), "The Significance of Welding Tests," 7 pp.

Discusses tests of static strength, ductility and impact strength.

(*w*) E. Lang (University of Melbourne), "The Development of the Welded Plate Girder," 6 pp.

Describes the author's view of the design of welded plate girders.

(*x*) F. Faltus (Skoda), "Design of Welded Structures with Special Regard to Erection on the Site," 7 pp.

(*y*) Hartmann and Girkmann (Vienna Technische Hochschule), "The Present Position of Welding in Structural Engineering in Austria," 8 pp.

Discussion of the Austrian welding specifications, the type of welded construction being built, and the investigations that have been made. A number of interesting points receive comment.

(*z*) Bainbridge and Clarke (Murex Welding Processes), "The Technical and Metallurgical Aspects of Flame Cutting," 12 pp.

Among other things, this article reports tests of butt-welded joints with flame cut edges to determine the effect of welding on flame-cut surfaces.

(*aa*) W. T. Everall (India), "Specification for Metallic Arc Welding as Applied to Mild Steel Bridge Work on the North-Western Railway, India," 8 pp.

(*bb*) W. T. Everall (India), "Specification for Electrodes for Use on Mild Steel Bridge Work on the North-Western Railway, India," 6 pp.

(*cc*) W. T. Everall (India), "Report on the Experiments Carried Out on Riveted Joints Strengthened by Electric Arc Welding," 6 pp.

Static tests with strain measurements.

(*dd*) R. A. Stephen (London), "The X-ray Examination of Welds," 10 pp.

Instructions for the use of X-ray equipment in weld testing by a representative of a manufacturer of X-ray equipment.

(*ee*) Colam, Watson and Lingard (India), "Welding onto a Member Which Is Already Stressed," 13 pp.

Experiments to investigate the permanent and consequent change in stress distribution by welding onto a stressed member.

61. N. G. Schreiner, "The Behavior of Fillet Welds When Subjected to Bending Stresses," *Journal of the American Welding Society*, Sept. 1935.

This is a report rendered to the Structural Steel Committee, American Bureau of Welding, and presents the results of tests of fillet welds under loading conditions to which they are commonly subjected, namely, those giving rise to combined bending and shearing stresses in the weld. The welds investigated covered lengths from $1^1/_2$ to 10 in. and fillet sizes of $^3/_8$ and $^1/_2$ in. Two types

of lightly coated and two types of heavily coated electrodes were included in the twenty-seven specimens tested. The loads were applied in such a manner that in approximately half the specimens the welds were under pure bending moment, while the other specimens, the duplicates of the first group, were loaded so that the welds were subjected to bending moment and vertical shear. In addition tensile tests on specimens cut entirely from the fillet welds were made, from which the physical properties and specific gravity of this deposited metal were determined. The ultimate bending moments observed are plotted against the section modulus and are compared with the calculated resisting moments of the welds. It is shown that the ratio of the modulus of rupture of the welds to their ultimate strength, as determined by the standard end-fillet qualification specimen, averages 1.87 for lightly coated electrodes and 1.61 for heavily coated electrodes. The results of the second series, in which the welds were subjected to average vertical shears up to eighty per cent of their ultimate shearing strength, show very little decrease in bending resistance in comparison with similar specimens in which no vertical shear was present.

The chief conclusions that are drawn on the basis of these results are:

1. That the factor of safety, the ratio of the observed ultimate strength to the designed strength, of welds subjected to combined bending and shearing stresses in these tests is at least seven.

2. That the vertical shearing stresses in the weld are of small importance in comparison to the bending stresses. As long as the weld is adequate to resist the bending, it is adequate for vertical shears of the magnitude allowed by present specifications, and will still give a factor of safety of seven.

3. That the use of heavily coated electrodes increases the bending resistance of the weld in approximately the same proportion as the tensile resistance is increased.

4. For the $^3/_8$- and $^1/_2$-in. fillet welds tested, the bending resistance increases directly as the increase in fillet size.

62. "Arc-Welded Bridge Girders Tested to Failure," LaMotte Grover, *Eng. News-Record*, **115**, 392–394 (1935).

Describing tests to destruction of two full-size welded built-up plate girders, 54 in. deep and 27 ft. long with butt-welded flange splices. These test specimens exhibited no distress in welds and good stress distribution up to the point of failure.

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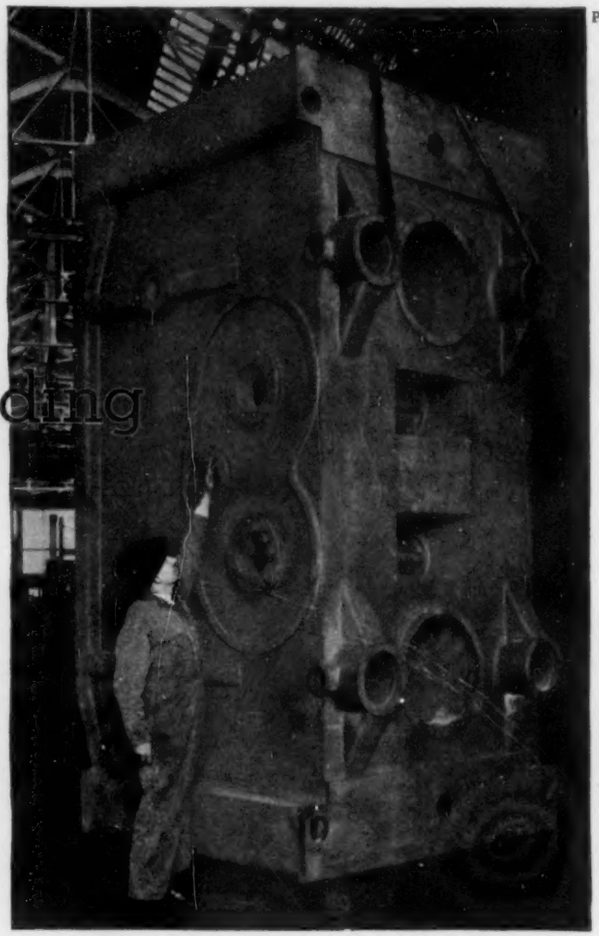

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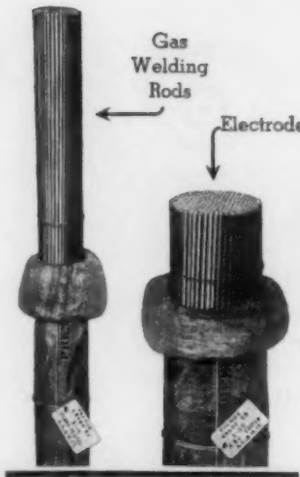

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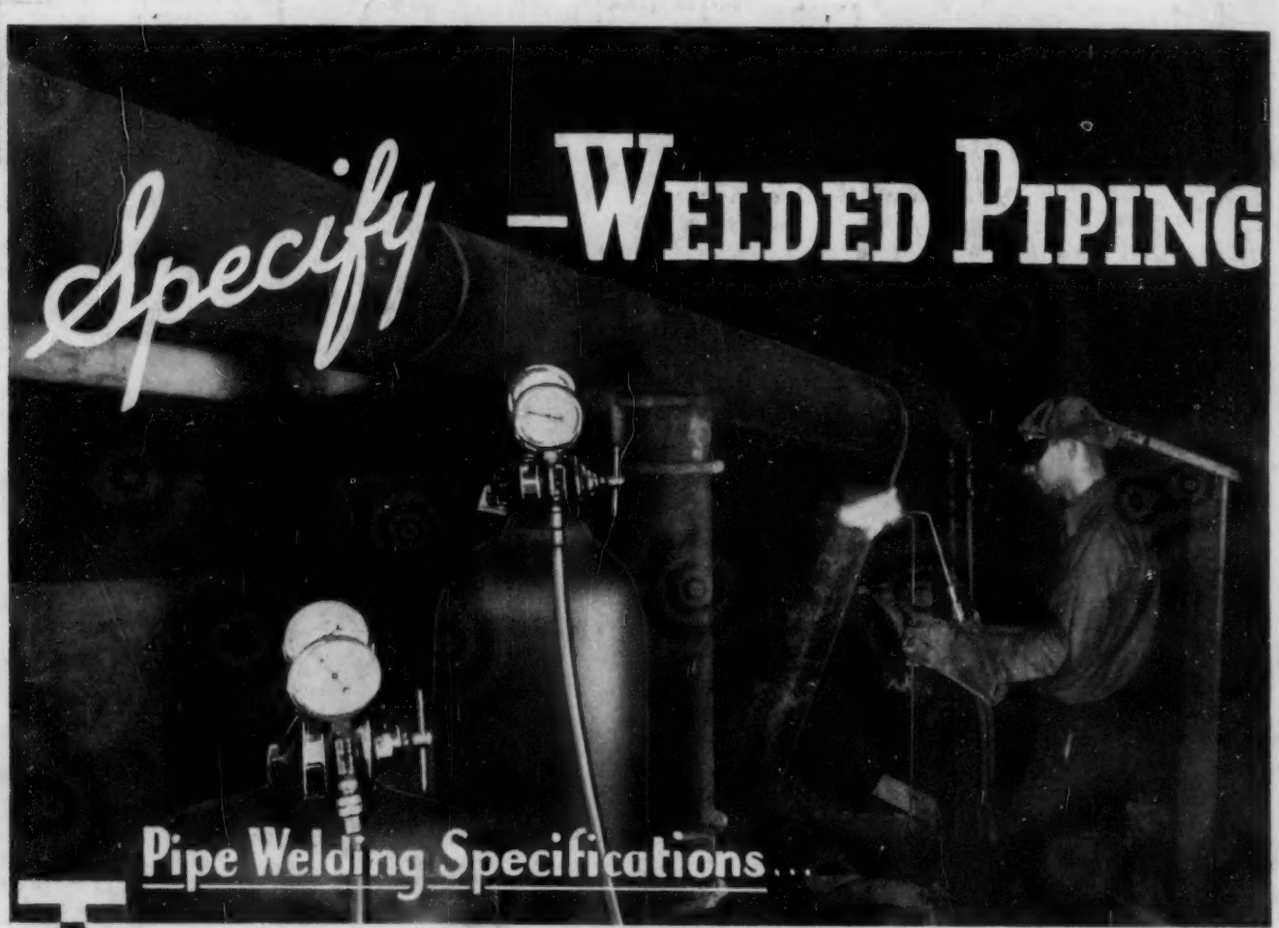

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